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THE ELEMENTS OF SIR ISAAC NEWTON'S PHILOSOPHY

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OF
SIR ISAAC NEWTON'S
PHILOSOPHY

VOLTAIRE

TRANSLATED BY
JOHN HANNA

FRANK CASS & CO. LTD.
1967

Published by
FRANK CASS AND COMPANY LIMITED
67 Great Russell Street, London WC1

First published in French	1738
First published in English	1738
New impression with index	1967

REF
QA
803
.V613
1967
Cop. 1

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Publisher's Note to the 1967 Edition

This is an exact reproduction of the 1738 edition of Voltaire's *The Elements of Sir Isaac Newton's Philosophy*. An index, prepared under the General Editor's supervision, has been added.

THE

ELEMENTS

OF

Sir ISAAC NEWTON's PHILOSOPHY.

By Mr: VOLTAIRE.

Tranſlated from the FRENCH.

Reviſed and Corrected
By *JOHN HANNA*, M. A.
Teacher of the Mathematicks.

With Explication of ſome Words in Alphabetical Order.

Pulchre ſibi diſputare videntur, cum quod evertere non poſſunt, tanquam ridiculum contemnunt.
Horroccius.

LONDON:

Printed for STEPHEN AUSTEN at the *Angel* and *Bible* in St. *Paul's Church-Yard.*

MDCCXXXVIII.

M. VOLTAIRE

TO THE

MARCHIONESS du CH**

IMMORTAL Emily, vaſt, pow'rful Mind,
Pallas of *France*, and Glory of thy Kind,
Surpaſſing Age, ev'n in thy Bloom of Youth,
The Pupil, Friend, of *Newton*, and of Truth.
Thy Fires tranſpierce me, and thy Charms controul;
I feel the Force, the Brightneſs of thy Soul!
To Thee attracted, I renounce the Bays
Sought on the Stage, while yet I liv'd on Praiſe.
My Wit, corrected, roves not as before,
Of vain Applauſe, idolatrous no more!
Let Earth-born *Rufus* with Reſentment rave,
And drag his ſenſeleſs Fury to the Grave.
In Rhyme ſtill ſtraining, coldly to encloſe
Some trivial Thought, that would depreciate Proſe,

15 That harmleſs Thunder let him hurl at me,
Which firſt his Rage for others might decree.
To blaſt my Fame let Pedant *Zoilus* ſeek,
And ſpread unmeaning Malice once a Week.
With me their Envy withers in the Bud;
20 I ſee no Tracts imprinted in the Mud.
Philoſophy, all-charming, pow'rful Queen,
Lifts the wiſe Mind above corroding Spleen.
Happy on high, where *Newton* now remains,
Knows He on Earth if Enmity yet reigns?
25 Not more than He my Enemies I know,
While Truth auguſt invites me from below.
Already ſee! ſhe opes the Gate of Day!
The Liſts I enter, and purſue my Way!
The maſſy Whirlpools, heaving ſtill for Place,
30 Heap'd without Rule, and moving without Space,
Thoſe learned Phantoms vaniſh from my Sight,
And Day comes on me with her genuine Light!
That vaſt Expanſe, of Being the Abode,
Space, which contains th' Infinity of God,
35 Sees in her Breaſt this bounded Syſtem move
Of Planets, Worlds, beneath us and above,
Whoſe whole Extent, ſo wondrous to our Senſe,
Is but a Point, an Atom in th' Immenſe.

God ſpeaks, and Chaos at his Voice ſubſides;
In various Orbs the mighty Maſs divides:
At once they gravitate, they ſtrive to fall,
One Center ſeeking, which attracts them all.
That Soul of Nature, that all-moving Spring,
Lay long conceal'd, an unregarded Thing;
'Till *Newton*'s Compaſs, moving thro' the Space
Meaſures all Matter, all diſcover'd Place;
Finds Motion's Cauſe, Philoſophy unleavens,
Lifts up the Veil, and open'd are the Heavens.
His learned Hand unfolds the glitt'ring Robe,
That clothes yon lucid, animated Globe,
Who guides the Seaſons, and who rules the Day.
Mine Eyes diſtinguiſh each emitted Ray.
With Purple, Azure, Emerald, and Roſe,
Th' immortal Tiſſue of his Habit glows.
Each Emanation, in pure Subſtance, bears
The various Colours that all Nature wears:
Thoſe blended Taints illuminate our Eyes,
Give Life to Matter, fill th' expanded Skies.
Eternal Pow'rs, who, near the King of Kings,
Burn with his Fires, and cover with your Wings.

His Throne; O tell us! viewing *Newton*'s Plan,
Were you not jealous of that wond'rous Man?
The Sea too hears him. With ſtupendious Dance
I ſee the humid Element advance!
Tow'rds Heav'n it riſes; Heav'n attracts it high:
But central Pow'r, more potent, as more nigh,
Each Effort ſtops: The Sea recoils; it roars;
Sinks in its Bed, and rolls againſt the Shores.
Ye Comets, dreaded like the Bolts of Jove,
In vaſt Ellipſes regularly rove!
Ceaſe with your Motion Mortals to affright:
Remount, deſcend near the great Orb of Light:
Elance your Fires; fly; and, as each appears,
Reſtore the Vigour of exhauſted Spheres!
Thou, Siſter of the Sun, who, in the Skies,
Of dazzled Sages mock'd the feeble Eyes
Newton has mark'd the Limits of thy Race:
March on; illumine Night; we know thy Place.
Earth, change thy Form; let the great Law of Matter,
The Pole depreſſing, elevate th' Equator!
Pole, fix'd to Sight, avoid the frozen Car,
The Conſtellation of the Northern Bear:

Embrace, in each of thy immenſe Careers,
Almoſt two thouſand Centuries of Years[*]!
How beautiful theſe Objects! how the Mind 85
Flies to theſe Truths, enlighten'd and refin'd!
Yes, in the Breaſt of God, from Matter free,
It hears the Voice of that eternal He.
Thou, whom that Voice familiarly invites,
Say, ev'n in Youth, the Seaſon of Delights, 90
How haſt Thou dar'd, in ſpite of Cuſtom's Force,
To move ſo boldly, thro' ſo vaſt a Courſe?
To follow *Newton* in that boundleſs Road,
Where Nature's loſt, and ev'ry Thing but God?
Purſuing Thee, I venture to advance, 95
And bring home Truth, that Wanderer, to *France.*
While *Algaroti*[†], ſure to pleaſe and teach,
Conducts the Stranger to the Latian Beach,
With native Flow'rs adorns the beauteous Maid,
And *Tyber* wonders at ſuch Worth diſplay'd; 100

---

[*] *Almoſt two thouſand Centuries.*] Mr. *Voltaire's* Line is
Deux cens ſiecles entiers par delà ſix milleans.
But the Period he is ſpeaking of, according to his own Account of it, conſiſts of 194000 Years, which is almoſt two thouſand Centuries.

[†] *Algaroti.*] A young *Venetian*, who is now printing at *Venice* a Treatiſe on Light, in which he explains Attraction.

I graſp the Compaſs, and the Out-lines trace,
And with coarſe Crayons imitate her Face.
Th' immortal Fair, all ſimple, noble, grand,
Should I attempt it, my unſkilful Hand
To Her, as Thee, no Luſtre could impart,
Above all Praiſe, and far above my Art.

THE

PREFACE.

IT ſeems to have been the Deſign of the Author in the following Treatiſe to give only a Taſte of Sir Iſaac Newton*'s natural Philoſophy to thoſe who have heard his Works much commended, but had not enough of Mathematical Learning to read them; tho' there are in ſeveral Places ſeveral curious Things to entertain the more Learned.*

The Author himſelf hath obſerved ſeveral Errors in the French *Edition, printed at* Amſterdam; *and therefore it was neceſſary in this Edition, which is taken from it, to make ſeveral Amendments, tho' perhaps ſome may be wanting ſtill; particularly in Page* 12. *Line* 10. *where it's ſaid the Diſtance of the Stars is as their apparent Magnitude inverſly, ſome may think it ſhould be the Square of their Diſtance; but even that would not be true, except* *their real Magnitudes were all equal, which is ſcarcely credible; a few others were marked with the Errata, which may be ſoon helped.*

The Reader is at Liberty to paſs over the few Remarks at the Bottom of ſome Pages, tho' they were inſerted by one who is neither a rigid Newtonian *nor* Carteſian, *and ſo no Party Man; for* Amicus Plato, Amicus Ariſtoteles, ſed magis amica veritas. *There are not only the Prejudice of Education, but alſo Intereſt, the Eſtimation of others, and Selfconceit, that give a great Biaſs to the Judgment, and ſometimes* Decipimur ſpecie recti. *This Treatiſe may ſerve to rectify the Judgment of thoſe that can bear to read any thing againſt it.*

THE

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ERRATA.

PAGE 170. *Line* ult. *for* directed *read* deceived.
P. 170. *l.* ult. *for* ſuſpended *r.* ſuperadded.
P. 172. *l.* 9. *for* Eclipſes *r.* Ellipſes.
P. 173. *l.* ult. *for* good *r.* hold good.
P. 144. *l.* 8. *at the Beginning, r.* reflects, ***and dele*** nothing.
P. 160. *l.* 5 *r.* abſolute Gravity.

TO THE

MARCHIONESS of CH**

INTRODUCTION.

MADAM,

NEITHER your Title, nor the Philoſophy here treated, are imaginary. Your ſolid Study of many new Truths, and the Fruits of ſo meritorious an Application, are what I now offer the Publick for your own, and the Glory of your Sex, and for the Improvement of all ſuch as deſire to cultivate their Reaſon, and enjoy without difficulty the Benefit of your Enquiries. Graces and Beauties are not to be expected here. Every Hand is not capable of covering the Thorns of the Sciences with the Flowers of Wit and Fancy; and for my part I ought to make it my ſole Endeavour in this Eſſay to conceive certain Truths aright, and to explain them with Order and Perſpicuity: To attempt to adorn them, were encroaching upon your Province.

The Name of new Philoſophy would be no more than the Title of a new Romance, if it implied only the Conjectures of a Modern in oppoſition to the Notions of the Ancients. A Philoſophy, founded only upon accidental Explications advanced at a venture, would not in ſtrictneſs deſerve the leaſt Examination. For the Methods of arriving at Error are innumerable, whilſt there is but one Way that leads to Truth; it is therefore the odds of infinite to one, that a Philoſopher, who ſupports his Principles only by Hypotheſes, will advance nothing but Chimera's. Hence it is, that all the Ancients, who have treated Phyſicks without the light of Experiments, have been only the Blind explaining the Nature of Colours to the Blind.

This Tract will not be a compleat Courſe of Phyſicks. That were to make it immenſe; a ſingle part of Phyſicks employing the Lives of many Men, and often letting them die in Uncertainty.

You confine yourſelf in the Study, of which I treat, ſolely to forming a clear Idea of thoſe ſubtle and powerful Springs, thoſe primary Laws of Nature, diſcovered by *Newton*;

ton; to examining how far others had gone before him, from whence he ſet out, and where he ſtopped. We ſhall begin like him with Light, which, tho' the moſt ſubtle of all Bodies, and that which approaches the neareſt to infinitely little, is however the Body of which we know the moſt. It has been traced in its Motions and Effects; it has even been anatomized and ſeparated into all its poſſible Parts. Of all Bodies, it is that which moſt explains the Secrets, and brings us the neareſt to the firſt Springs, of Nature.

We ſhall endeavour to make theſe Elements eaſy and intelligible to thoſe, who know no more of *Newton* and Philoſophy than their Name. The Knowledge of Nature is a Good, to which all Men have an equal Right: all are for knowing their Good, which few have Time or Patience to calculate; this *Newton* has done for them. Here we muſt ſometimes content ourſelves with the total of thoſe Calculations. A publick Man, a Miniſter, every day forms a juſt Idea of the reſult of Operations not in his own Power to execute; the Eyes of others have ſeen, the Hands of others have laboured for him, and enable him by faithful Reports to paſs his Judgment. Every Man of Wit will be here almoſt in the ſame caſe with this Miniſter.

Newton's Philoſophy has hitherto ſeemed to many as unintelligible as that of the Ancients; but the Darkneſs of the *Greeks* proceeded from their having in reality no Light at all, whilſt that of *Newton* ariſes from his Light's being too remote from our Eyes. He has diſcovered Truths; but he has ſearched for, and placed them in an Abyſs, into which it is neceſſary to deſcend, in order to bring them out, and to place them in full Light.

The Reader will find here all thoſe Truths which tend to eſtabliſh the new Property of Matter diſcovered by *Newton*. We ſhall be obliged to ſpeak of ſome Singularities which occur in the courſe of our Deſign; but we ſhall not loſe Sight of our End.

Thoſe who deſire to inſtruct themſelves more at large, may read the excellent Phyſicks of *Graveſande*, *Keil*, *Muſchenbroek* and *Pemberton*, and approach to *Newton* by degrees.

CHAP. I.

What Light is, and in what manner it comes to us.

Singular Definition of the Peripateticks.

THE *Greeks*, and after them all the barbarous Nations, who learnt of them to reaſon and to err, have ſaid from Age to Age thro' a long ſeries of Time; " Light is " an Accident, which Accident is the act of " Tranſparent as Tranſparent; Colours are " what move tranſparent Bodies. Luminous " and coloured Bodies have Qualities " like thoſe they excite in us, according to " the Maxim, that nothing can give what it " has not. In fine, Light and Colours are " a mixture of the hot, cold, dry and humid; " for the humid, dry, cold and hot, " being the Principles of all Things, Colours " muſt neceſſarily be compoſed of them."

This is the abſurd Jargon, which the Profeſſors of Ignorance, paid by the Publick, have made human Credulity revere for ſo many Ages; which manner of reaſoning prevailed almoſt in all things down to the times of *Galileo* and *Deſcartes*. Even long after them the ſame Traſh, the Diſgrace of human Underſtanding, ſubſiſted in many Schools. I dare aver that human Reaſon, ſo obſcured, is far below the narrow indeed, but certain, Perceptions, which in Brutes we call Inſtinct. Hence we cannot congratulate ourſelves too much on our good Fortune in being born at a Time, and amongſt a People, in which, and with whom Mankind begin to open their Eyes, and to enjoy the nobleſt Inheritance of Humanity, the Uſe of Reaſon.

All the pretended Philoſophers therefore having gueſt of Nature at a venture thro' the Veil, under which ſhe lay concealed, *Deſcartes* at length came, and diſcovered a Corner of that great Veil. He ſaid: Light is a fine and ſubtle Matter diffuſed univerſally, that ſtrikes our Eyes. Colours are Senſations excited in us by God, according to the Motions which tranſmit that Matter to our Organs. Thus far *Deſcartes* was in the right, and ought either to have ſtopped there, or in advancing, to have taken Experiment for his Guide. But he was poſſeſſed with the deſire of eſtabliſhing a Syſtem. That Paſſion had the ſame effect on this great Man, as Paſſions have

The Fondneſs for eſtabliſhing a Syſtem miſled Deſcartes.

have on all Men; they hurry them beyond their Principles.

He had laid down as the firſt Principle of his Philoſophy, that nothing ſhould be believed without Evidence; and yet, in Contempt of his own Rule, he imagines three Elements formed of pretended Cubes, which he ſuppoſes to have been made by the Creator, and to have been broken to pieces in turning upon themſelves, after they came out of the Hands of God. Theſe three imaginary Elements are, as every body knows,

His Syſtem.

1. The moſt denſe parts of theſe Cubes; of which groſs Element, according to him, the ſolid Bodies of the Planets, the Seas, and even the Air are compoſed.

2. The imperceptible Duſt, which the breaking to pieces of theſe Dice had produced, and which fills to Infinitude the Spaces of the infinite Univerſe, in which he ſuppoſes no Vacuum, or Void.

3. The Middles of theſe pretended Dice broken to pieces, equally attenuated on all ſides, and at laſt made round into Balls, of which he thinks fit to make Light, and which he diffuſes abundantly throughout the Univerſe.

Falſe. The more wittily this Syſtem was imagined, the more the Reader will perceive it unworthy of a Philoſopher. For, as nothing of all this is proved, it were full as reaſonable to admit the cold and hot, the dry and humid. What does it ſignify which of the two Errors be preferred! We will not loſe time in diſputing this creation of Cubes and three Elements, or rather this Chaos. Let us content ourſelves with obſerving here the Philoſophical Errors into which the Syſtematical Spirit, or Fondneſs for Syſtem carried the ſublime Genius of *Deſcartes*; and let us refute eſpecially only thoſe Errors, which having the air of Truth, have gained Credit, and deſerved to be advanced.

According to *Deſcartes*, the Light does not proceed to our Eyes from the Sun, but is a globulous Matter diffuſed univerſally, which the Sun impels, and which preſſes upon our Eyes as a Staff puſhed at one end preſſes the ſame inſtant at the other. This appeared plauſible, but is not therefore the leſs falſe: *Deſcartes* however was ſo fully convinced of this Syſtem, that in his ſeventeenth Letter of the third Volume, he poſitively ſays and repeats it: *I confeſs that I know nothing of Philoſophy, if the Light of the Sun is not tranſmitted to our Eyes in an inſtant.* And indeed, we muſt own, that as great a Genius as he was, he knew very little of true Philoſophy; and wanted the Experiments of the ſucceeding Age. That Age is as much ſuperior to *Deſcartes*, as *Deſcartes* was to Antiquity.

Of the progreſſive Motion of Light.

1. If Light were always diffuſed, and always exiſting in the Air, we ſhould ſee as clearly in the Night as we do in the Day, becauſe the Sun below the Hemiſphere would continually impel the Globules on all ſides, and the Impreſſion equally affect our Eyes.

2. It is demonſtrated, that Light flows from the Sun, and we know, that it is very near ſeven or eight Minutes in coming to us from ſo immenſe a diſtance, which a Cannon-bullet retaining its force could not do in five and twenty Years.

Error in Spectacle de la Nature.

The Author of the *Spectacle de la Nature*, a Work of great Merit, has fallen in this point into a ſmall Miſtake, which no doubt he will correct in the next Edition of his Work. He ſays, that Light, according to *Newton*, is ſeven Minutes in coming to us from the Stars;

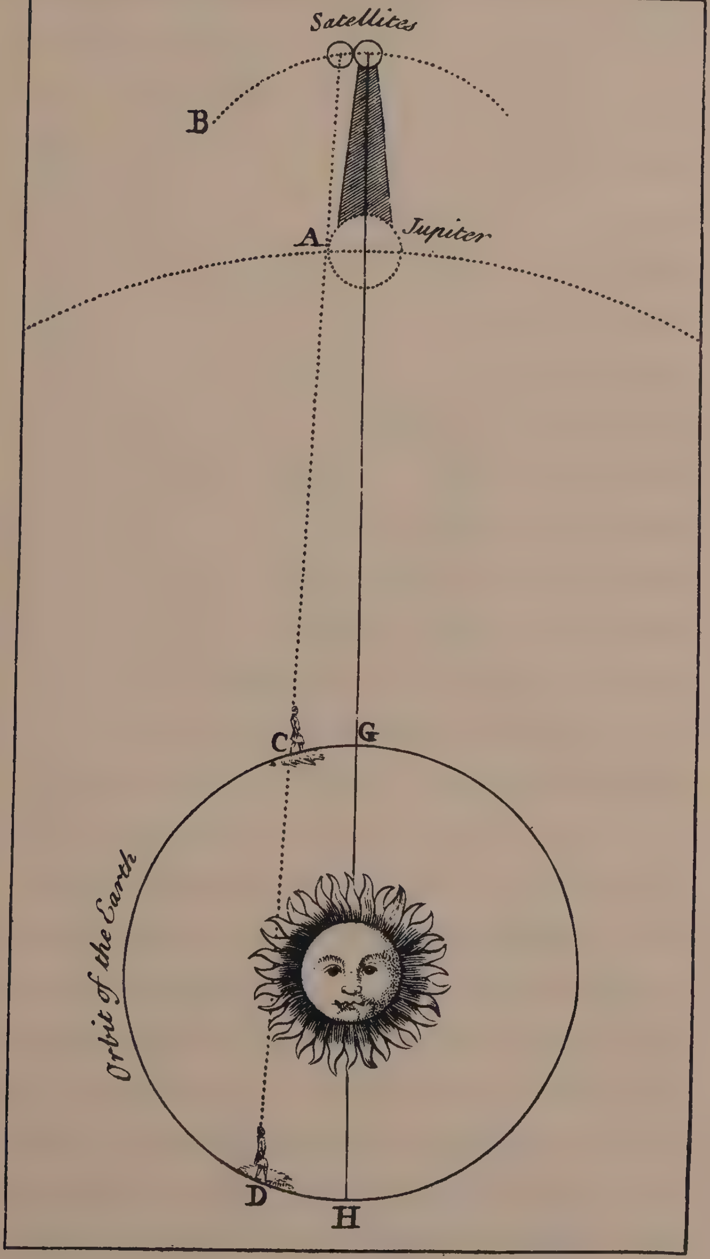
he has taken the Stars for the Sun. Light is ſix Months in coming to us from the neareſt of them, according to a certain Calculation, founded upon Experiments very delicate, and at the ſame time very imperfect. It is not *Newton*, but *Huygens* and *Hartſoeker*, who have advanced this Suppoſition: he ſays alſo, to prove that God created Light before the Sun, *That Light is diffuſed throughout all Nature, and makes itſelf ſenſible, when the luminous Stars impel it*; but it has been demonſtrated to be very long in coming from the fixed Stars to us. Now, if it comes ſo far, it was not diffuſed before. It is neceſſary to be aware of theſe Errors, which are every day repeated in abundance of Books, that are a kind of Ecchoes to each other.

The following is in a few words the Subſtance of *Romer*'s ſenſible Demonſtration, that Light employs ſeven or eight Minutes in its Paſſage from the Sun to the Earth.

Demonſtration of the Motion of Light.

From the Earth at C, a Satellite of *Jupiter* is obſerved to be eclipſed regularly once in two and forty Hours and an half. If the Earth were immoveable, the Obſerver at C would ſee thirty Emerſions of that Satellite in thirty times two

Pag. 10.



two and forty Minutes and an half; but at the end of that time the Earth is come to D, and then the Obſerver ſees no longer that Emerſion exactly at the end of thirty times two and forty Hours and an half; but muſt add the time, which Light takes in paſſing from C to D, which time is manifeſtly conſiderable. But this ſpace C D is leſs than the ſpace G H, for C D is a Chord of the Circle, and G H its Diameter. This Circle is the great Orbit deſcribed by the Earth around the Sun in the Center; Light in coming from the Satellite of *Jupiter* paſſes the Chord C D in ten Minutes, and G H in fifteen or ſixteen. The Sun is between G and H; the Light therefore is ſeven or eight Minutes in coming from the Sun.

Mr. *Bradley*, in the laſt place, has obſerved by reiterated and certain Experiments, that many Stars viewed at different times, appeared ſometimes a little more towards the South, and ſometimes a little more towards the North; which difference, he has proved, could ariſe only from the annual Motion of the Earth, and the Progreſſion of Light. He obſerves, that if theſe Stars have a Parallax, it can be only of one Second.

Admitting this, I proceed to reaſon in the following manner: a Star, whoſe annual Parallax is no more than of one Second, is four hundred thouſand times more remote from us than the Sun; if Light be eight Minutes in coming from the Sun to us, as Mr. *Bradley* believes, it will in conſequence be ſix Years, and above a Month, in coming to us from thoſe Stars. But this is not all. Theſe are Stars of the firſt Magnitude, thoſe therefore of the ſixth, being ſix times more diſtant, cannot tranſmit their Light to us in leſs than thirty ſix Years and an half.

3. The Rays, diverted and forced to take a new Courſe by a Priſm, demonſtrate, that Light actually moves, and is not a Quantity of Globules or Balls ſimply preſt.

4. If Light conſiſted of Globules exiſting every where in the Air, a ſmall hole cut in a dark Chamber ought to illuminate it entirely: for Light impelled in every manner thro' the little Hole would act on all ſides, as Balls of Ivory diſpoſed in a circular or ſquare Form would diſperſe themſelves on all ſides, if only one of them were ſtrongly moved; but directly the contrary happens. For the Light

received at a ſmall Hole, which admits but few Rays to paſs thro' it, ſcarce illuminates half a Foot of the place upon which it falls.

5. The Light always enters a Hole in a right Line, in whatever manner the Hole can be contrived; but if the Balls were ſimply preſſed, it would be impoſſible for that Preſſure to be in a right Line. It is evident therefore, that *Deſcartes* is miſtaken as well in regard to the Nature of Light, as the manner in which it is tranſmitted to us.

F. Mallebranche's *Error.*

Father *Mallebranche*, whoſe Genius was more ſubtile than true, and who always conſulted his Meditations, but not always Nature, adopted the Elements of *Deſcartes* without Proof; but he made ſome Alterations in that inchanted Caſtle. He imagined without other Proof another Explanation of Light.

The Vibrations of luminous Bodies impreſs, according to him, Strokes or Motions upon ſmall and gentle Whirlings, capable of Compreſſion, and entirely compoſed of ſubtile Matter. But had *Mallebranche* been aſked, in what manner theſe ſmall and gentle Whirlings tranſmitted Light to our Eyes; how the Sun's Action could paſs in an inſtant thro'

thro' ſo many ſmall Bodies compreſſed upon one another, of which a very ſmall number were ſufficient to intercept that Action; and laſtly how it happened, that thoſe gentle Whirlings did not mingle in turning upon one another: What would that Father have replied? Upon what Foundation did he build this imaginary Superſtructure? Should Men who talked of nothing but *Truth*, have wrote nothing but Romances!

Definition of Light. What then at length is Light? It is *Fire itſelf*, which burns at a ſmall diſtance when its Parts are leſs attenuated, or more rapid, or more united; and which gently illuminates our Eyes, when it acts from a greater diſtance, and its Particles are more rare, and leſs rapid, and leſs united.

Thus a lighted Candle would burn the Eye at the diſtance of only ſome Lines (twelfths) of an Inch, and gives it Light at that of ſome Inches. Thus the Rays of the Sun, diffuſed thro' the Spaces of the Air, illuminate Objects, and collected by a Burning-Glaſs melt Lead, Gold, *&c.*

This Fire is darted on all ſides from the Point irradiating: which is the cauſe of its being ſeen on all ſides; it is therefore always to be conſidered, as Lines iſſuing from a Center to a Circumference. Thus every Irradiation, or Groupe of Rays, from the Sun or any Fire whatſoever, ſhould be conſidered as a Cone, of which the Baſe is upon our Eye, and the Vertex at the Fire that darts it.

This Matter of Fire is thrown from the Sun to us, and as far as *Saturn*, &c. with a Rapidity that amazes the Imagination.

The Calculation of it ſhews, that if the Sun is four and twenty thouſand Semi-diameters of the Earth from us, Light in its Progreſſion to us from that Star, is but a Second in coming about a thouſand million of Feet. Now a Bullet of a Pound Weight, diſcharged with half a Pound of Powder, flies but ſix hundred Feet in a Second; ſo that a Ray of the Sun (to make the Numbers even) is one million, ſix hundred and ſix thouſand, ſix hundred times more rapid than a Cannon-ball.

I ſhall not enter here into the famous Diſpute *De vivis viribus*; I refer the Reader for that to the learned and profound Diſſertation of Mr. *Mairan*, *See Memoirs of the Academy,* &c. 1728.

I hope that Philoſopher, and thoſe who moſt oppoſe the Doctrine of living Powers, will permit me with the utmoſt Rigour to advance the following Propoſition.

The Effect produced by the Force of a Body in motion, at leaſt when uniform in its Rapidity, is the Product of its Quantity by the Square of its Acceleration; that is to ſay, that a Body, if it has ten Degrees of Swiftneſs, will *(cæteris paribus)* make an hundred times as much Impreſſion as it would do, if it had only one Degree of Swiftneſs.

Extreme minuteneſs of the Particles of Light.

If therefore a ſingle Particle of Light acts in proportion to the Square of its Swiftneſs, and if that Force is about ſixteen hundred thouſand to that of a Bullet, that Square will be 2560000000000, it follows then, if that Atom is only two billions, five hundred and ſixty thouſand millions of times leſs than a Pound, it will however have the ſame Effect as a Cannon-ball. Suppoſe this Atom ſtill a thouſand millions of times leſs; one Moment's Emanation of Light would deſtroy all the Vegetables upon the Face of the Earth. Imagine how ſmall a Particle of Light is, which paſſes ſo eaſily through Glaſs; and to have ſome Idea of Infinite, conceive what that Matter ſtill a million of Degrees more ſubtile muſt be, that enters the Pores of Gold and the Loadſtone, and penetrates the Rocks and the Bowels of the Earth.

The Sun which darts this luminous Matter to us in ſeven or eight Minutes, and the Stars, thoſe other Suns, which tranſmit it to us in ſeveral Years, ſupply us eternally without waſting almoſt in the ſame manner, as the Creature that produces Muſk, perpetually emits odoriferous Bodies around it, without any ſenſible diminution of its Weight.

In fine the Rapidity, with which the Sun projects its Rays, is in proportion to its Magnitude, which is about a million to one, to that of the Earth, and to the Swiftneſs of the Motion, with which that immenſe Body of Fire turns round upon its own Axis in twenty five Days and an half.

The Force, Illumination, Intenſeneſs and Denſity of all Light is calculated. This Calculation ſhews, that this Force is exactly in proportion to the Force, with which Bodies fall, and with which *Newton* proves all the heavenly Bodies attract one another. This

Proportion in which all Light acts.

Proportion is called the inverſe Rule of the Square of the Diſtances. It will be neceſſary to familiarize ourſelves with this Expreſſion. Its Signification is ſimple and intelligible: it is, that a Body at the diſtance of four Feet from any Fire, will be ſixteen Times leſs heated and illuminated, than a Body at the diſtance of one Foot, ſixteen is the Square of Four. Now Four is the diſtance of the Body leſs illuminated; the Light therefore tranſmits to this Body diſtant four Feet, not four but ſixteen Times leſs Rays. And this is called the Ratio, or Rule, inverſe of the Square of the Diſtances, which ought to be well underſtood; for this Proportion will be one of the Principles, on which the New Philoſophy is founded, which we ſhall endeavour to make eaſy.

Progreſſion of Light. Proof of the Impoſſibility of a Plenum.

We may here take occaſion to conclude from the Rapidity, with which the Subſtance of the Sun tranſmits itſelf to us in this manner in a right Line, how chimerical the Plenum of *Deſcartes* is. For firſt, how could it come to us in a right Line, thro' ſuch immenſe Spaces of Matter moved in a curve Line, and thro' ſuch an Infinity of different Motions? 2. How could ſo rare a Body in ſeven or eight Minutes paſs thro' the Space of thirty millions of Leagues between us and the Sun, if it was to penetrate a reſiſting Matter all the way. In that Caſe every Ray muſt diſplace thirty millions of Leagues of ſubtile Matter in a Moment. Beſides which, we are to remember, that this pretended ſubtile Matter would reſiſt in the abſolute Plenum, as much as the moſt ſolid Matter. For a Pound of Gold-duſt, preſſed cloſe in a Box, reſiſts as much as a piece of Gold weighing a Pound. So that it would be neceſſary for a Ray of the Sun to have much greater Force, than if it were to penetrate thro' a Cone of Gold, of which the Axis ſhould be thirty millions of Leagues.

Experience, that true Guide of Philoſophy, further ſhews us, that Light in coming from one Element into another, from one Medium into another, does paſs through entire, as we ſhall obſerve: a great Part of it is reflected; the Air repelling more of it than it tranſmits; ſo that it would be impoſſible for the Light of any of the Stars to reach us; it would be wholly repelled and abſorbed, before a ſingle Ray could come half way to our Atmoſphere. But in the Chapters, where we ſhall explain the Principles of Gravitation, we ſhall prove by a multitude of Arguments, that this pretended Plenum was a Romance.

Let us here ſtop a Moment to obſerve how ſlowly Truth eſtabliſhes itſelf amongſt Mankind.

It is almoſt fifty Years ſince *Romer* demonſtrated by Obſervations upon the Satellites of *Jupiter*, that Light is tranſmitted from the Sun to the Earth in about ſeven Minutes and an half, notwithſtanding which the contrary is not only maintained in many Books of Phyſicks; but in a Collection upon that Subject in three Volumes extracted from the Obſervations of all the Academies in *Europe*, printed 1730, pag. 35, Vol. I. there is this Paſſage.

" Some have pretended, that a luminous
" Body as the Sun, emits continually an
" Infinity of ſmall inſenſible Particles, which
" bring the Light to our Eyes; but this
" Opinion, which ſtill ſavours a little of
" the old Philoſophy, cannot be maintain-
" ed."

This Opinion is however demonſtrated in more than one manner, and is ſo far from ſavouring of the Old Philoſophy, that it is directly contrary to it; for can any thing be more contrary to Words void of Senſe, than Meaſures, Calculations and Experiments?

CHAP. II.

The Property, which Light has of reflecting itſelf, was not truly known. It is not reflected by the ſolid Parts of Bodies as vulgarly believed.

HAVING ſeen what Light is, from whence derived, and how long it is in coming to us, let us proceed to its Properties and Effects, unknown till our Days. The firſt of its Effects, is its ſeeming to rebound from all Objects to bring the Images of them to our Eyes.

All Men, all Philoſophers, *Deſcartes*, *Mallebranche*, and ſuch as are moſt remote from vulgar Opinion, have equally believed, that the ſolid Surfaces of Bodies are what actually reflect Light to us. The more ſmooth and ſolid a Surface is, the more, they ſay, it cauſes the Light to rebound from it; the larger, and the more direct the Pores of the Body are, the more the Rays of Light paſs thro' its Subſtance. Thus the Looking-glaſs, covered at bottom with a Surface of Quickſilver, reflects all the Rays; and the ſame

Glaſs without Quickſilver, having direct and large Pores in great number, lets great part of the Rays paſs thro' it. The more large and direct Pores a Body has, the more tranſparent it is: ſuch is, ſaid they, the Diamond, ſuch the Water itſelf; and theſe were the Ideas generally received, which no-body called in queſtion.

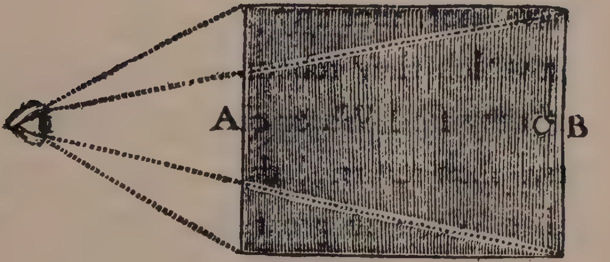
Yet all theſe Ideas are entirely falſe, ſo remote often is the Likeneſs of Truth from the Truth itſelf. The Philoſophers gave into this Error, in the ſame manner the Vulgar entirely miſtake, when they imagine the Sun no larger than it appears to the Eye. In this conſiſted the Error of the Philoſophers:

There is no Body, whoſe Surface we can really make even. However the Surfaces of many ſeem perfectly ſmooth and poliſhed: and whence do they appear ſo to us? The moſt ſmooth Superficies, in reſpect to the Particles, of which Light is compoſed, is no more than a great number of Mountains, Cavities, and Spaces, ſo that the Microſcope diſcovers, that the Point of the fineſt Needle actually abounds with Eminences and rugged Parts.

All the various Rays of Light, which ſhould fall on theſe unequal Parts, would be reflected according as they ſhould fall, and falling unequally, would never be regularly reflected, for which reaſon we could never ſee ourſelves in a Glaſs.

The Light therefore, which preſents us our Image in a Looking-glaſs, undoubtedly does not proceed from the ſolid Parts of the Superficies of that Glaſs; neither is it the Effect of the ſolid Parts of the Mercury Pewter ſpread upon its Back. Thoſe Parts are not more even or more ſmooth than the Glaſs itſelf. The ſolid Parts of the Pewter and Mercury are incomparably larger than the conſtituent ſolid Parts of Light, therefore if the ſmall Particles of Light fall upon the groſs Parts of the Mercury, they will ſpread and ſcatter themſelves on all ſides, like Grains of Lead falling upon Rubbiſh. What unknown Power then is it, that cauſes Light to rebound towards us with ſo much Regularity? It appears already, that Bodies do not return it in this manner. What ſeemed the moſt known and inconteſtible amongſt Mankind, becomes a greater Myſtery than the Weight of the Air was formerly. Let us examine this Problem of Nature, and our Wonder will encreaſe. We cannot inform ourſelves in it without Surprize.

Take a ſmall piece, a Cube of Cryſtal, and you will find the Rays of the Sun fall on this ſolid tranſparent Body in this manner.



1. A ſmall part of the Rays rebound to the Eye from the neareſt Surface A, even without touching that Surface, as will be proved more at large.

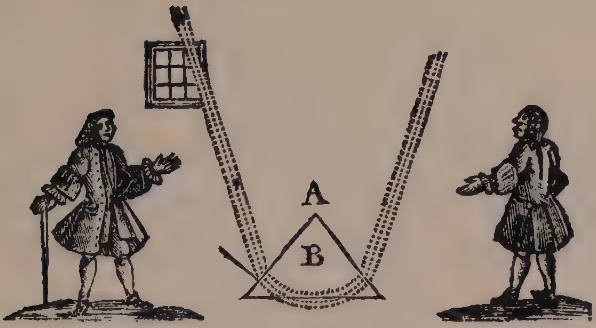
2. Part of the Rays are received into the Subſtance of this Body, where they play, loſe themſelves, and extinguiſh.

3. A third Part reach to the Inſide C of the Surface B, and from near the Surface B return into A, from whence ſome come to the Eye.

4. A fourth Part paſſes into the Air.

5. A fifth Part, which is the moſt conſiderable, returns from beyond the fartheſt Surface B into the Cryſtal, which it repaſſes, and comes to reflect itſelf to the Eye. Let us here examine theſe latter Rays, which having paſſed the fartheſt Surface B, and come to the Air, fly back from that Air towards us, re-entring thro' the Cryſtal. They undoubtedly have not met any ſolid Parts in that Air, on which they rebounded; for inſtead of Air, if they find Water on that Surface, few of them then return; they enter and penetrate that Water in great abundance. Now Water is about eight hundred Times heavier, more ſolid, and leſs rare than Air. Theſe Rays however do not rebound from this Water, but they rebound from that Air into the Glaſs; therefore the Light is not reflected by the ſolid Parts of Bodies.

The following is a more ſingular and more deciſive Obſervation. Expoſe in a dark Chamber this Cryſtal A B, to the Rays of the Sun in ſuch a manner, that the Light coming on the Superficies B, makes an Angle of above forty Degrees with the Perpendicular.



Deciſive Experiments.

Moſt of the Rays then penetrate into the Air no longer, they re-enter the Cryſtal the inſtant they quit it, they return, as you ſee, but in a Curve not Perceptible.

It certainly is not the ſolid Surface of the Air that repels them into the Glaſs; many of thoſe Rays entered the Air before, when they fell leſs obliquely; why therefore with an Obliquity of forty Degrees, nineteen Minutes, do moſt of thoſe Rays paſs no longer? Do they find more Reſiſtance, more Matter in the Air at this Degree, than in the Cryſtal they had penetrated? Are there more ſolid Parts in the Air at forty Degrees and one third, than at 40? The Air is almoſt two thouſand four hundred Times more rare, leſs weighty, and leſs ſolid than the Cryſtal, thoſe Rays therefore ought to paſs into the Air with two thouſand four hundred Times more Facility, than they penetrated the Subſtance of the Cryſtal. However, notwithſtanding this prodigious appearance of Facility they are repelled; but then repelled here by a Force two thouſand four hundred Times greater than that of the Air; they therefore are not at all repelled by the Air; again, the Rays are not reflected to our Eyes by the ſolid Parts of Matter. For Light rebounds ſo little from the ſolid Parts of Bodies, that in reality it rebounds from Vacuity.

We have juſt ſeen, that Light falling in an Angle of 40 Degrees 19 Minutes upon the Cryſtal, rebounds almoſt entirely from the Air, which it finds at the fartheſt Surface of the Cryſtal. Let Light fall on it, in an Angle leſs only one Minute, ſtill leſs of it will paſs beyond that Surface into the Air. Remove the Air, and no Rays at all will paſs. This is a thing demonſtrated.

Now when there is Water upon this Surface, many Rays enter that Water, inſtead of being reflected by it. When there is only Air fewer Rays enter that Air. When there is no Air, no Ray paſſes; it is therefore from the Vacuum that Light is reflected.

Here then are undoubted Proofs, that it is not a ſolid Superficies that reflects Light to us: there are many other Proofs ſtill of this new Truth; of which the following is one, we ſhall explain in its Place. Every opaque Body reduced to a thin Plate, ſuffers Rays of a certain kind to paſs through its Subſtance, and reflects other Rays: now, if Light were reflected by Bodies, all the Rays which ſhould fall upon theſe Plates, would be reflected by them. To conclude, we ſhall ſee that ſo aſtoniſhing a Paradox never had a greater variety of Proofs. Let us begin then by familiarizing ourſelves with theſe Truths.

1. This Light, which is imagined to be reflected by the ſolid Surface of Bodies, returns in Effect without having touched that Surface.

2. Light is not reflected from the Back of a Looking-glaſs by the ſolid Surface of the Quickſilver, but from the very Pores of the Looking-glaſs and the Quickſilver.

3. It is not neceſſary, as it has hitherto been thought, that the Pores of that Quickſilver

ſhould be very ſmall to reflect Light; on the contrary, it is neceſſary that they ſhould be large.

To thoſe who have not ſtudied this Philoſophy, it will be new matter of Surprize to hear it ſaid, that the Secret of rendering a Body opaque, is often to enlarge its Pores, and that the Means to make it tranſparent, is to make them ſmall. The Order of Nature appears entirely changed: what ſeemed the neceſſary Cauſe of Opacity, is directly the Cauſe of Tranſparence; and what appeared to render Bodies tranſparent, is become what makes them opaque. Nothing however is more true, as the groſſeſt Experiment demonſtrates.

A piece of dry Paper, of which the Pores are very large, is opaque, no Ray of Light paſſing thro' it: reduce thoſe Pores, by making it imbibe Water or Oil, it becomes tanſparent; as will alſo Linen, Salt, *&c.*

There are then certain unknown Principles, which produce theſe Wonders, certain Cauſes, which occaſion Light to rebound, before it touches a Surface, which reflect it from the Pores of tranſparent Bodies, and which repel it from the very midſt of Vacuity; we are inevitably obliged to admit theſe Facts, whatever the Cauſe of them may be.

Let us then apply ourſelves to the other Myſteries of Light, and let us ſee whether theſe ſurprizing Effects may be traced to ſome inconteſtbile Principle, which we muſt neceſſarily admit as well as the Effects themſelves.

CHAP. III.

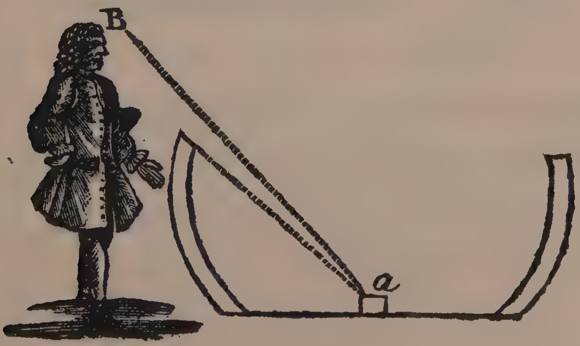
Of the Property which Light has of refracting in paſſing from one Subſtance into another, and of taking a new Courſe in its Progreſſion.

THE ſecond Property of the Rays of Light, which it is neceſſary to examine well, is that of taking a new Direction in its Paſſage from the Sun into the Air, from the Air into Glaſs, from Glaſs into the Water, *&c.* It is this new Direction in theſe different Mediums, or breaking of the Light, which is called Refraction, by which Property an Oar in the Water appears crooked to the Rower; it is that occaſions our ſeeing the Object in a Bowl, by putting Water in it, which we could not ſee before at the ſame Place.

In ſhort it is by the means of this Refraction that our Eyes enjoy Sight. The admirable Secrets of Refraction were unknown to the Ancients. Notwithſtanding its being before their Eyes, and their perpetual Uſe of it, they have not left us a ſingle Tract, to induce us to believe that they had gueſſed the reaſon of it. Thus to this Day we ſtill continue ignorant even of the Cauſe of the Motions of our Bodies, and of the Thoughts of our Souls; but this Ignorance is of a different kind. We neither have nor ever ſhall have Inſtruments of ſo exquiſite a Frame, as to enable us to inſpect the firſt Springs, the vital Principles of ourſelves; but human Induſtry has formed itſelf new Eyes, which has ſupplied us with the means of prying into the Effects of Light, almoſt as far as it is permitted for Man to know concerning them.

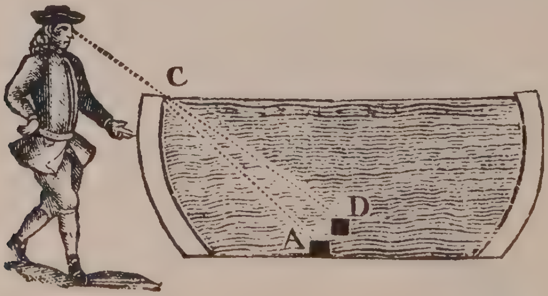
In what manner Light is refracted.

Let us here form a clear Idea of a very common Experiment. Suppoſe a piece of Gold in this Baſon, and your Eye fixed on the ſide of the Baſon, at ſuch a diſtance, that you cannot ſee the Piece:



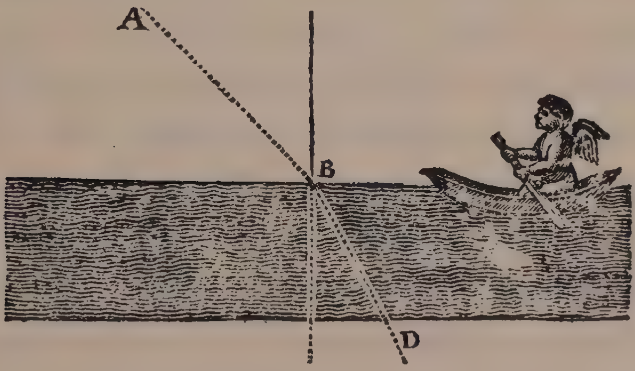
Let Water be poured into it, you did not ſee the Money at firſt where it was: but now you ſee it where it is not; how happens this?

The Object A reflects a Ray, which ſtrikes the ſide of the Baſon, and which will never reach your Eye: it alſo reflects the Ray A B, which paſſes above your Eye; but when you receive this Ray A C, it is not your Eye that has changed its Place, but it is the Ray A C; that has manifeſtly taken a new Direction at the Edge of the Baſon in paſſing from the Water into the Air, and thereby ſtrikes your your Eye from C.



For you always ſee Objects in a right Line, therefore you ſee the Object in the right Line C D, and at the Point D, above the Place where it really is.

If this Ray is broke in one manner, when it paſſes from the Water into the Air, it muſt break in a contrary manner, when it enters the Water from the Air.



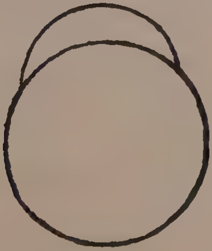
I raiſe a Perpendicular from this Water; the Ray, from the luminous Point A is broke at the Point B, and approaches the Perpendicular in the Water by the Line B D. The ſame Ray D B in its Progreſſion from the Water into the Air, is broke in paſſing towards A, and removing from the ſame Perpendicular; Light therefore is refracted differently, according to the Mediums through which it paſſes. It is upon this Principle that Nature has diſpoſed the different Humours in our Eyes, in order that the Rays of Light, in their Paſſage thro' thoſe Humours, may be broke in ſuch a manner, as to reunite after in a Point upon the Retina: to conclude, it is upon the ſame Principle, Spectacles are made, which occaſion ſtill greater Refractions than thoſe of the Eye, and which, thereby uniting a greater number of Rays, are capable of adding about two hundred Times more Force to the Sight; in the ſame manner as the Invention of the Leaver has augmented the Force of our Arms, which are natural Leavers. We were going to explain the reaſon diſcovered by *Newton*, of this Property of Light; but it is neceſſary to know firſt in what manner this Refraction acts in our Eyes, and how the Senſe of Sight, the moſt extenſive of all the Senſes, owes its Exiſtence to Refraction. How well ſoever we conceive this Matter, it will not be amiſs to ſtrengthen the Reader's Ideas of it by a new Enquiry. Thoſe who peruſe this little Work, will not be diſpleaſed with having no occaſion to ſeek elſewhere for what they may deſire to know concerning the Sight.

CHAP. IV.

Of the Form of the Eye, and in what manner Light enters and acts in that Organ.

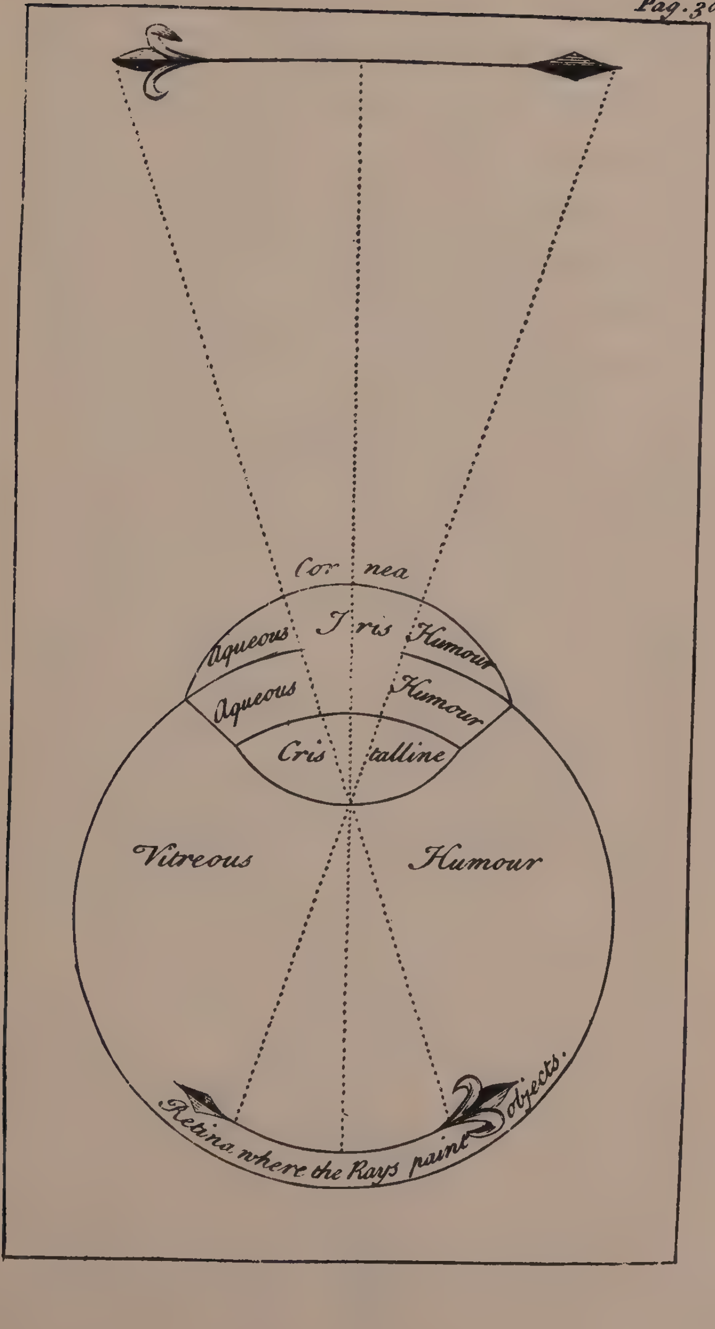
TO know the Eye of a Man as a Philoſopher who conſiders only Viſion, it is neceſſary to know firſt, that the firſt white Cover or Coat, the Defence and Ornament of the Eye, tranſmits no Rays. The ſtronger and ſmoother this White of the Eye is, the more Light it reflects; and when ſome warm Paſſion brings unuſual Spirits to the Viſage, they ſtrain and actuate this Membrane in ſuch a manner that the Eyes ſeem to flaſh like Fire.

In the midſt of this Membrane, the Cornea of the Eye raiſes itſelf a little, being thin, hard and tranſparent, exactly like the Glaſs of a Watch, when placed upon a Bowl in this manner.



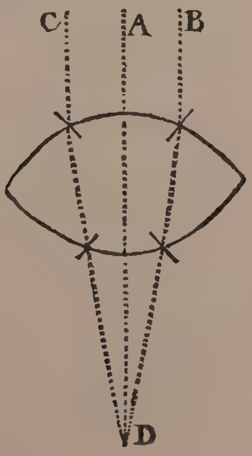
Under this *Cornea*, is the *Iris* another Membrane, which being coloured of itſelf, diffuſes its Colour upon this tranſparent *Cornea* that covers it. It is from this *Iris*, ſometimes blue and ſometimes brown, that the Eyes are either blue or black. It is perforated in the middle, which therefore always appears black, and is called the Sight of the Eye. Through this opening the Rays of Light enter; it enlarges itſelf by an involuntary Motion in dark Places for the reception of more Rays, and contracts again, when too much Light offends it.

The Rays admitted through this Sight are before conſiderably refracted in paſſing through the *Cornea* with which it is covered. Imagine this *Cornea* like the Glaſs of a Watch, that is Convex without, and Concave within: all oblique Rays are broke in paſſing this Glaſs; but afterwards its Concavity re-inſtates what its Convexity has broke. This is what happens in the *Cornea*. The Rays ſo broke and diſperſed, after having paſſed the *Cornea*, find a tranſparent Humour into which they enter. This is called the *Aqueous Humour*. The Anatomiſts do not agree amongſt themſelves


Cor nea
Aqueous
Iris
Humour
Aqueous
Humour
Cristalline
Vitreous
Humour
Retina where the Rays paint objects.

ſelves concerning the Form of this little Reſervoir. But, whatever its Figure be, Nature ſeems to have placed this clear and limpid Humour there, to cauſe Refractions, to tranſmit the Light clearly, and that the Cryſtalline Humour which is behind it may advance without difficulty, and change Figure freely, and that the neceſſary Humidity be preſerved, *&c.*

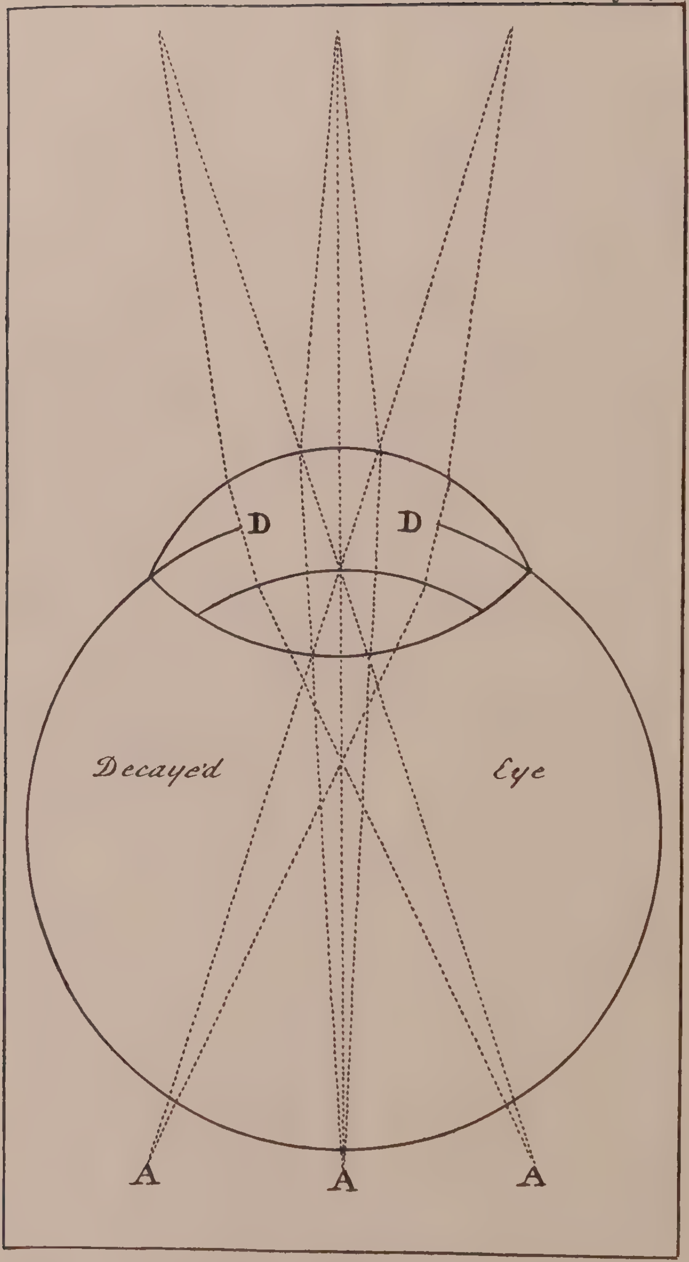
The Rays having paſſed this Water, come to a kind of liquid Diamond, in the Form of a Lentil, and ſet in a fine Membrane, which is itſelf tranſparent. This Diamond is the *Cryſtalline Humour*, that breaks all oblique Rays, and is the principal Organ of Refraction and Sight; in that reſpect perfectly like a Spectacle-glaſs of the ſame Form. Suppoſe this Figure the Cryſtalline Humour or Lenticular Glaſs.



The perpendicular Ray A penetrates it, without being broke; but the oblique Rays B, C, break in paſſing this Glaſs, approaching the perpendicular Rays which are drawn here on the Places where they fall. Afterwards, when they quit the Glaſs to paſs into the Air, they break again removing as you ſee from the Perpendicular; this new Refraction is exactly what makes them converge in D, the Focus of the Lenticular Glaſs.

Now the *Retina*, that ſlight Membrane, that Expanſion of the Optick Nerve, which covers the bottom of the Eye, is the Focus of the Cryſtalline Humour: it is to this *Retina* that the Rays tend; but before they reach it, they again meet a new Medium through which they paſs; this new Medium is the Vitreous Humour, leſs ſolid than the *Cryſtalline*, but not ſo fluid as the *Aqueous.*

In this Vitreous Humour the Rays have time to aſſemble before their laſt Union upon the Points of the bottom of the Eye. Imagine then under this Lenticular *Cryſtalline*, the Vitreous Humour ſupporting it; that Humour holds the *Cryſtalline* in its Concavity, and is round towards the *Retina.*



Eye, in which the Cristalline is flat thro age or disease.

The Rays in paſſing this laſt Humour finally Converge. Every Groupe of Rays, that iſſues from a Point of an Object, ſtrikes upon a Point of the *Retina.*

A Figure in which each Part of an Eye is marked with its proper Name, will better explain all this Mechaniſm, than Lines and A's or B's can do. The Structure of the Eyes being thus underſtood, the reaſon why the aid of Glaſſes is ſo often neceſſary, and the Uſe of Spectacles, may eaſily be known.

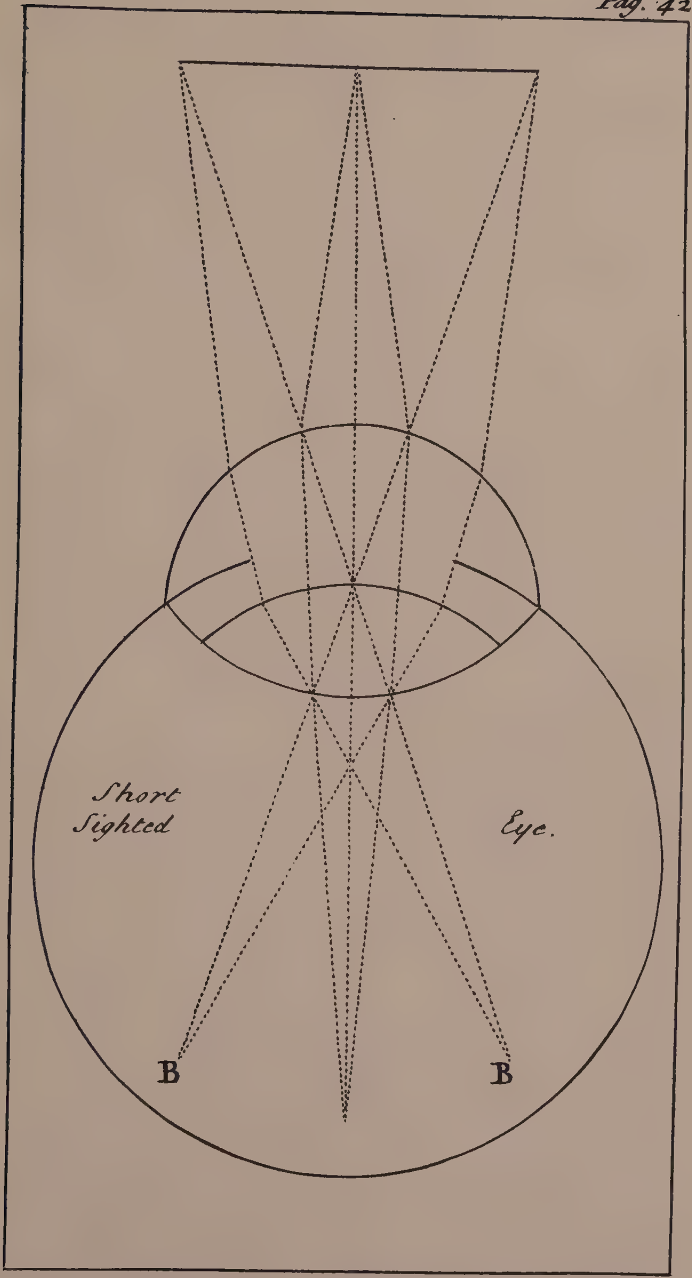
Decayed Eye.

An Eye will often be too flat either thro' the Formation of the *Cornea*, or its Cryſtalline Humour, which Age or Diſeaſe may have dried up; the Refractions will then be too weak and in leſs Quantity, nor will the Rays be collected any longer upon the *Retina.* Let us conſider this too flat Eye, and call it for Diſtinction ſake the *Decayed Eye.*

For the greater Facility, let us obſerve only three Groupes or Cones of Rays falling from the Object on this Eye. They will reunite at the Points A, A, A, beyond the *Retina*, and in Conſequence the Objects will be ſeen confuſed.

Nature has ſupplied an Help againſt this Inconvenience, by the Power ſhe has given the Muſcles of the Eye either to lengthen or make it flat, to make it approach or withdraw from the *Retina*. Thus in this decayed Eye, the *Cryſtalline Humour* has the Faculty of advancing itſelf a little to D D: the Space then between it and the bottom of the *Retina* becomes greater, and the Rays are brought to unite upon the *Retina*, inſtead of going beyond it; but when that Power is loſt, human Induſtry ſupplies it, and a Lenticular Glaſs is placed between the Object and the decayed Eye. The Effect of this Glaſs is to draw the Rays it receives cloſe together, which it conveys to the Eye both more collected and in greater Number: theſe reach the *Retina* in the Points they ought, and the Sight is then clear and diſtinct.

Short-ſighted Eye. Obſerve this other Eye, which has a contrary Defect, it is too round. The Rays unite too ſoon, as you ſee at the Point B, they croſs each other too faſt, they ſeparate in B, and from thence go on to make a Spot upon the *Retina*. This is called *Shortneſs of Sight*. This Inconvenience decreaſes in proportion



Eye, in which the Criſtalline is too round, and occaſions Shortneſs of Sight.

portion as Age brings on others, ſuch as Dryneſs and Weakneſs: theſe inſenſibly render this too round Eye flat, for which reaſon ſhort-ſighted Eyes are ſaid to laſt the longeſt. At this time the Perſon, who was obliged to bring his Book to the Diſtance of two or three Inches from his Eye, can ſometimes read at that of a Foot; but at the ſame time his Sight ſoon becomes troubled and confuſed, and he cannot ſee diſtant Objects; ſuch is our Condition, one Defect can ſcarce ever be repaired but by another.

Now, whilſt this Eye is too round, it is neceſſary to uſe a Glaſs, which prevents the Rays of Light from re-uniting too ſoon. This Glaſs will have a quite contrary Effect to the former, and inſtead of being Convex on both ſides, muſt be a little Concave on both ſides, to diſperſe the Rays, which the other collects. They will in Conſequence unite farther in the Eye, than they did before, and the Eye will ſee perfectly well. The Convexity, and Concavity of Glaſſes are proportioned to the Defects of the Eyes; the ſame Glaſſes, that ſuit the Eyes of one old Man, will be of no Service to another, for there are neither two Diſeaſes, two Men, nor two Things exactly alike in the World.

The Ancients did not know theſe Spectacles. They knew however Burning-Glaſſes; the Diſcovery of one Truth in a Subject, is not always a reaſon for the Diſcovery of all the Truths it includes. The Attraction of the Load-ſtone was known, but its Direction to the Pole remained a Secret. The Demonſtration of the Circulation of the Blood was evident, even in the Bleeding practiſed by all the Greek Phyſicians, notwithſtanding which no-body ſuſpected that the Blood circulated.

It is very likely that the Spectacles and Magnifying-Glaſſes, which give new Eyes to the Old, were diſcovered in the time of *Roger Bacon* in the 13th Century; for he is the firſt that ſpeaks of them.

You have now ſeen the Effects cauſed by Refraction in our Eyes, whether the Rays reach them without any intermediate Aid, or paſs thro' Cryſtals: you conceive, that without ſuch Refraction in our Eyes, and ſuch Reflection of Rays from above the Surfaces of Bodies, the Organs of Sight would be of no uſe to us. The Means employed by Nature in cauſing this Refraction, and the Laws ſhe obſerves, are Myſteries we are going to explain. But firſt we muſt conclude what we have to ſay concerning Sight, and ſatisfy theſe natural Queſtions? Why do we ſee Objects beyond, and not upon, the Looking-Glaſs? Why does a Concave Looking-Glaſs render Objects larger than they are? Why do Teleſcopes draw Things nigh and magnify them? By what Artifice does Nature make us ſenſible of Magnitudes, Diſtances and Situations? And laſtly, why do we ſee Objects as they are, tho' reverſed on our *Retina*? All theſe Things merit the Curioſity of every Thinking Being? but we ſhould not have enlarged upon Subjects, which ſo many Illuſtrious Writers have treated of, and ſhould have referred to them, if we had not in view the making known ſome Truths ſufficiently new, and curious to a ſmall number of Readers.

CHAP. V.

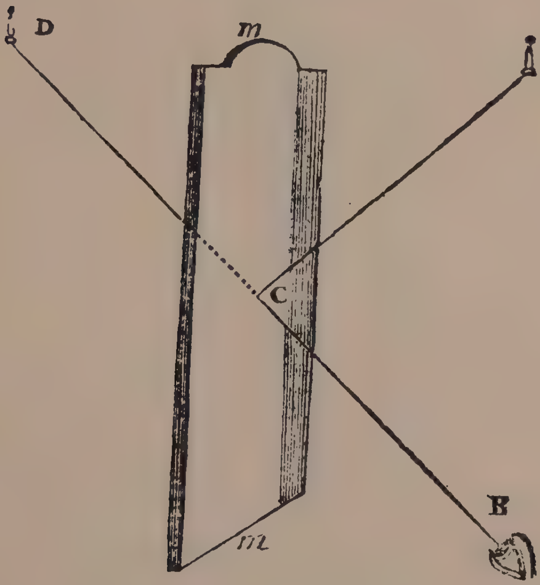
Of Looking-Glaſſes, and Teleſcopes: Reaſons given by Mathematicians for the Myſteries of Viſion; that thoſe Reaſons are not altogether ſufficient.

THE Rays, which a Power unknown till our Days, cauſes to reflect to the Eye from above the Surface of a Looking-Glaſs, without touching that Surface, and from the Pores of that Glaſs, without touching its ſolid Parts; theſe Rays, I ſay, return to the Eye in the ſame manner as they arrived at the Glaſs. If you ſee your Face in it, the Rays from your Face ſtriking parallel and almoſt perpendicular upon the Glaſs, return to it in the ſame manner as a Ball rebounds from the Floor.

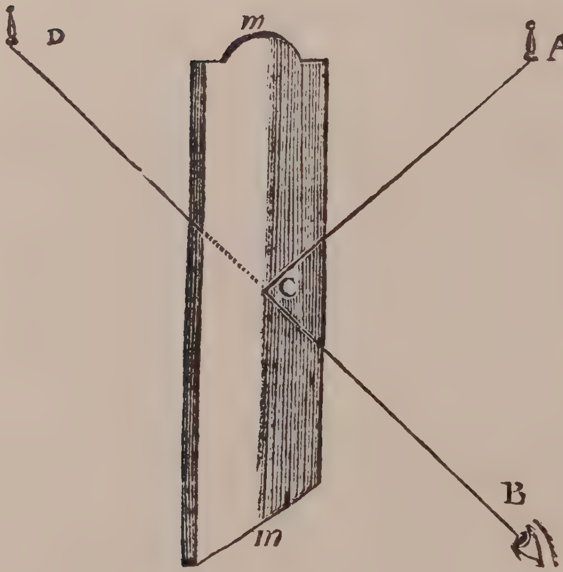
Looking-Glaſs with a plane Surface.

If in the Glaſs M, we look at an Object on one ſide of us as A, the Rays of that Object act in the ſame manner as a Ball, which ſhould rebound to B, the place of your Eye.

This is called the Angle of Incidence equal to the Angle of Reflection.

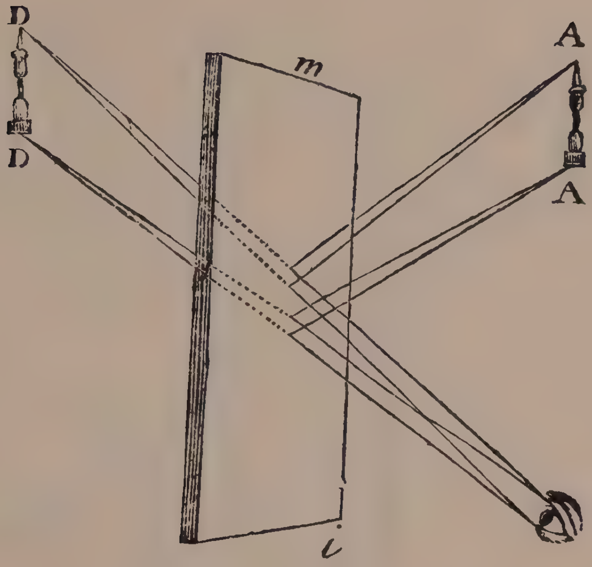


The Line A C is the Line of Incidence, the Line C B is the Line of Reflection. It is ſufficiently plain, and the bare mentioning demonſtrates, that thoſe Lines form equal Angles upon the Surface of the Glaſs; wherefore then do I not ſee the Object either in A where it is, or in C from whence the Rays come to the Eye, but in D behind the Glaſs?



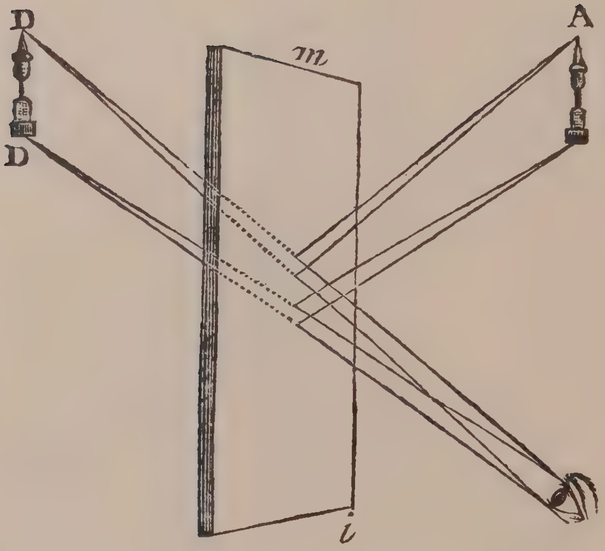
Geometry will tell us: that it is becauſe the Angle of Incidence is equal to the Angle of Reflection: becauſe the Eye in B, carries the Object into D; becauſe Objects can act upon you only in right Lines, and becauſe the right Line continued from your Eye B, behind the Glaſs to D, is as long as the Line A C, and the Line C B added together.

It will tell you alſo, that you never ſee Objects but from the Point where the Rays begin to diverge. Suppoſe the Mirror M I.



The Rays from every Point of the Object A, in Cones begin to diverge A the inſtant they quit the Object; they proceed to the Surface of the Glaſs: there each of thoſe Rays falls, diſperſes, and is reflected towards the Eye. The Eye carries them back to the Points D D, at the end of the right Lines, where the ſame Rays would meet; but in meeting at the Points D D, thoſe Rays act in the ſame manner, as at the Points A, A, where they begin to ſpread; therefore you ſee the Object A A at the Points D D.

Theſe Angles and Lines ſerve no doubt to make us underſtand this Artifice of Nature; but

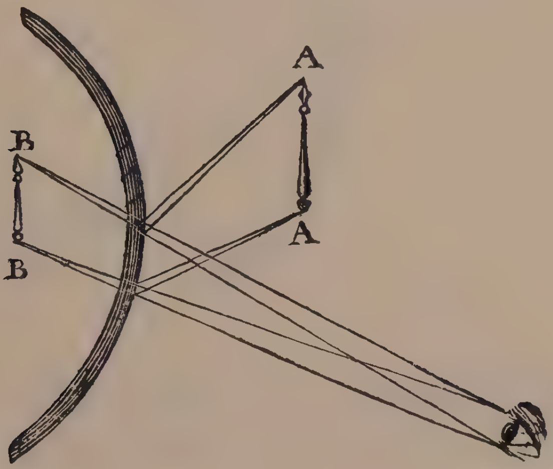


but they are far from informing us of the Phyſical Efficient Cauſe, why the Soul without heſitating carries the Object as far beyond the Glaſs as it is on this ſide of it. Theſe Lines repreſent what happens, but do not ſhew why it happens.

If you would know in what manner a Convex Glaſs diminiſhes, and a Concave Glaſs enlarges Objects, theſe Lines of Incidence and Reflection will give you the ſame Reaſon.

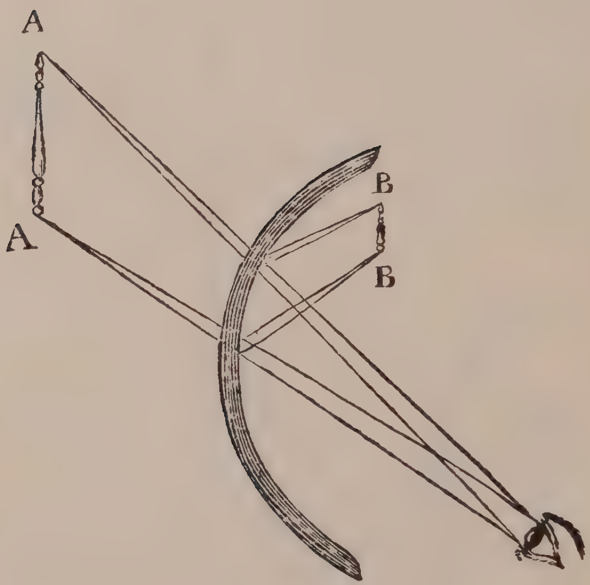
Convex Locking-Glaſs.

We are told; that the Cone of Rays, which diverge from the Point A, and fall on the Convex Glaſs, makes Angles of Incidence upon it equal to Angles of Reflection, of which Cone the Lines come to the Eye. Now theſe Angles are leſs, than if they had fallen on a plain Surface; therefore if they are ſuppoſed to paſs to B, they will meet or converge there much ſooner, and the Object in B B be ſmaller.



Now the Eye carries the Object to B B in Points, from which the Rays begin to diverge, therefore the Object muſt appear leſs, as it does in the above Figure. For the ſame reaſon that it appears leſs, it appears nearer, as the extreme Points of the Rays from B B, are actually nearer the Glaſs than thoſe of the Rays from A A.

By

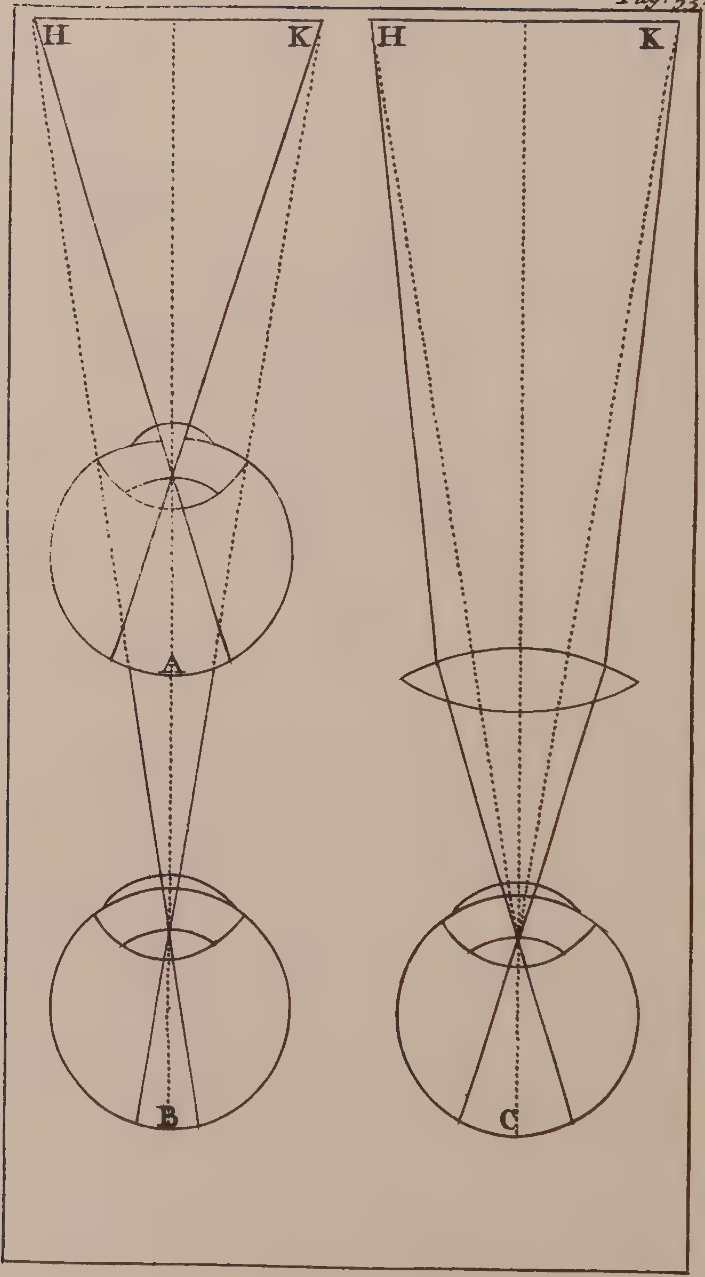


Concave Glaſs.

By the Rule of Contraries you muſt ſee Objects greater and more remote in a Concave Glaſs, when placed near enough to the Glaſs.

For the Cones of the Rays from B B, ſpreading upon the Glaſs at the Points where thoſe Rays fall, if they were reflected thro' that Glaſs, they would not unite but in A A, therefore they are ſeen in A A. Now A A is greater and morere mote from the Glaſs than B B, and therefore we ſee the Object greater and farther off.

This


H
K
H
K
A
B
C

This is in general what happens in the Reflection of Rays to our Eyes, and all the Myſteries of Catoptricks are founded on this ſole Principle, that the Angle of Incidence is always equal to the Angle of Reflection.

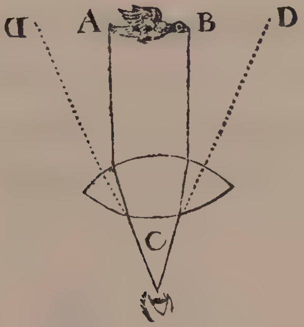
We are now to know in what manner Glaſſes augment, objects and leſſen Diſtances; and laſtly why Objects, that paint themſelves reverſed in our Eyes, ſhould however be ſeen as they are.

The Geometric Explication of Viſion.

In regard to Magnitudes and Diſtances, the Mathematicks inform us, that the greater the Angle is, which an Object makes in the Eye, the greater the Object will appear: nothing is more plain. The Line H K at an hundred Paces forms an Angle, as you ſee in the Eye A (Figure 1;) at two hundred Paces, it forms another leſs by one half in another Eye at B. Now the Angle formed on the *Retina*, or of which the *Retina* is the Baſe, is as the angle of which the Object is the Baſe. Theſe Angles are oppoſite at their Summits or Vertical Points; therefore, according to the firſt Notions of the Elements of Geometry, they are equal. Hence if the Angle formed in the Eye A, be double the Angle formed in the Eye B, the Object will appear as large again to the Eye A, as to the Eye B.

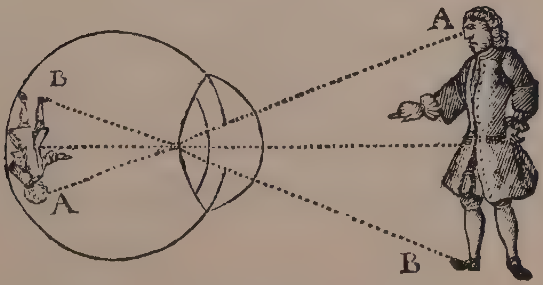
Now, that the Object may be ſeen as large by the Eye at B, as by the Eye at A, it is neceſſary to act in ſuch a manner, that the Eye B, may receive as large an Angle as the Eye A, which is as near again to it. The Glaſſes of a Teleſcope produce this Effect.

For the greater Facility let us ſuppoſe here only one Glaſs, and abſtract from the Effects of many Glaſſes. The Object H K (Figure 2) tranſmits its Rays to this Glaſs, which are united at ſome diſtance from it. Let us conceive a Glaſs ſo contrived, that thoſe Rays croſs one another in ſuch a manner, as to form in the Eye C, as great an Angle as that in the Eye A. The Eye then, you will ſay, judges by that Angle. It ſees the Object of the ſame Magnitude as the Eye in A. But in A it ſees it at the diſtance of an hundred Paces: therefore in C receiving the ſame Angle, it will ſtill ſee it at the ſame Diſtance. The whole Effect of multiplied Glaſſes, different Teleſcopes, and Microſcopes, which magnify Objects, conſiſts therefore in bringing Things to the Eye in a greater Angle. The Object A B, is ſeen by the means of a Glaſs in the Angle D C D, which is much greater than the Angle A C B.



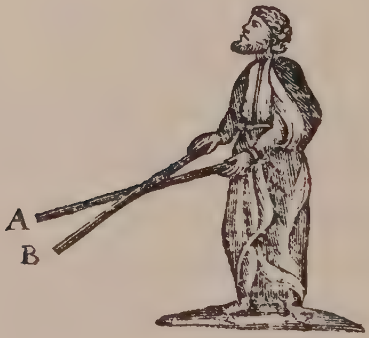
You aſk the Rules of Opticks again, why Objects, which are painted reverſed upon our *Retina*, are ſeen in their true Situation.

The Ray from the Head of the Man A, falls upon the lower Point of the *Retina* A, his Feet B are ſeen by the Rays B B, at the upper Part of the *Retina* B.



Thus the Man is really painted with his Head downwards and his Feet upwards at the bottom of our Eyes. Why therefore do we not ſee this Man reverſed, but upright and as he is?

To reſolve this Queſtion, the compariſon of a blind Man is uſed, who holds in his Hand two Sticks croſſed, with which he gueſſes very rightly of the Poſition of Objects:



For the Point B which is on the left, being felt by the Right Hand with the help of the Stick, he judges it immediately on the Left; and the Point A, which communicates with his Left Hand by the means of the other Stick, he judges on the Right without miſtake.

All the Maſters of Opticks tell us therefore, that the lower part of the Eye, immediately transfers its Senſation of the Object to the upper part A, and that the upper part of the *Retina*, as naturally tranſmits its Senſation to the lower part B, ſo that the Object is ſeen in its true Situation.

When we know perfectly well all the Angles and Mathematical Lines, by which the Paſſage of Light is traced to the bottom of the Eye, we are not to believe however that we know in what manner we attain our Perceptions of the Magnitudes, Diſtances, and Situations of Things. The Geometrical Proportions of thoſe Angles and Lines are juſt indeed; but there is no more relation between them and our Senſations, than between the Sound we hear, and the Magnitude, Diſtance, and Situation of the Thing heard. My Ear is ſtruck by Sound; I know the Notes and nothing more. My Eye is kept by Sight, I ſee Colours and nothing elſe. The Proportions of thoſe Angles and Lines cannot only be in any reſpect the immediate Cauſe of the Judgment I form of Objects; but in many Caſes, thoſe Proportions do not in the leaſt agree with the manner in which I ſee Objects.

For Inſtance, we ſee a Man of the ſame Size at four and eight Paces from us *. And yet the Image of that Man at four Paces is exactly twice as large in the Eye as at eight. The Angles are different; the Object is however of the ſame Dimenſions; it is evident therefore from this ſingle Example, out of many, that theſe Angles and Lines are far from being the immediate Cauſe of the manner in which we ſee.

Before therefore we purſue the Enquiries we have begun upon Light, and the Mechanick Laws of Nature, it is your Command, that I ſhould here ſhew in what manner the Ideas of Diſtances, Magnitudes, Situations, and Objects, are imparted to the Soul. This Enquiry will ſupply us with ſome new Truths, which is the only excuſe for a Book.

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* We judge him to be of the ſame Size, but do not ſee him ſo.

CHAP. VI.

In what Manner we know Diſtances, Magnitudes, Figures, and Situations.

Diſtance not known from the Angles and Lines of Opticks.

LET us begin with Diſtance. It is plain that it cannot of itſelf be immediately perceived; for Diſtance is no more than a Line from an Object to us. This Line terminates in a Point, we therefore perceive only this Point; and whether the Object be a thouſand Miles or only a Foot from us, the Point is ſtill the ſame.

We have not therefore any immediate Means of knowing Diſtance inſtantly, as we have by the Touch, of diſtinguiſhing whether a Body be hard or ſoft; by the Taſte, whether it be ſweet or bitter; and by the Ear, whether of two Sounds the one be grave and the other acute. The Idea of Diſtance therefore muſt be attained by the Means of ſome other intermediate Idea; but I muſt at leaſt have that intermediate Idea the ſame time; for an Idea that I have not, will certainly never occaſion my having another. I ſay ſuch a Houſe is a Mile from ſuch a River; but if I don't know where that River is, I certainly don't know where the Houſe is. A Body that eaſily receives Impreſſion from my Hand I conclude ſoft; another reſiſts, I immediately perceive its Hardneſs; it were therefore neceſſary, that I perceived the Angles formed in my Eyes, in Order to determine immediately the Diſtances of Objects from them. But nobody ever thinks of theſe Angles in looking at an Object. Moſt Men do not ſo much as know that there are ſuch: It is evident then theſe Angles cannot be the immediate Cauſe from which we know Diſtances.

Proved by an Example.

The Perſon who the firſt Time of his Life ſhould hear the Report of a Cannon, or the Harmony of a Concert, would not be able to judge whether that Cannon were diſcharged, or that Concert executed, at the Diſtance of a League or at that of thirty Paces. Only Experience can accuſtom him to judge of the Diſtance between him and the Place from whence thoſe Sounds come. The Vibrations, the Undulations of the Air, bring Sounds to his Ears, or rather to his Soul, but it apprizes his Soul no more of the Place where the Sounds began, than it inſtructs him in the Form of the Cannon, or of the Inſtruments of Muſick.

It is exactly the ſame Thing with Reſpect to the Rays of Light tranſmitted by an Object, they do not inform us at all how far that Object is.

Magnitudes and Figures not known by thoſe optick Lines.

They leave us no leſs in the Dark with Regard to Magnitudes, and even Forms or Figures.

I ſee at a great Diſtance a Kind of little round Tower. I go on, I perceive, and touch a great quadrangular Building. Certainly what I ſee and touch, is not what I ſaw before. The little round Object which I had in my Eye, is not this great ſquare Building.

Proved by an Example.

The meaſurable and tangible Object therefore is one Thing, and the Object of Viſion another. I hear in my Chamber the Noiſe of a Coach: I open my Window and ſee it; I go down and get into it. Now this Coach, which I have heard, this Coach which I have ſeen, and this Coach I have touched, is three abſolutely different Objects of three of my Senſes, which have no immediate Relation to each other.

But farther; it is demonſtrated, as I have ſaid before, that there is an Angle in my Eye twice as large, when I ſee a Man at four Feet from me, as when I ſee the ſame Man at eight. However, I always ſee this Man of the ſame Size: Whence is it, that my Perception contradicts the Mechaniſm of my Organs in this Manner? The Object is really as ſmall again in my Eyes, and I ſee it twice as large as it is. It is in vain to think of explaining this Myſtery by the Paſſage through the Cryſtalline, or the Form that Humour takes in our Eyes. Whatever Suppoſition we may make, the Angle in which I ſee a Man at four Feet from me, is always twice as large as the Angle in which I ſee him at eight; and Geometry will never ſolve this Problem.

Nor the Situation of Objects.

Theſe geometrical Lines and Angles are not more really the Cauſe that we ſee Objects in their Places, than that we ſee them of ſuch Magnitudes, and at ſuch Diſtances.

The Soul does not conſider whether ſuch a Part is to paint itſelf at the Bottom of the Eye, it's not concerned with Lines it does not ſee. The Eye only turns itſelf downwards to ſee what is near the Earth, and upwards to look at what is above it.

All this could only be explained, and made inconteſtible by ſome Perſon born blind, and reſtored to the Senſe of Sight. For if this blind Perſon, at the Moment he received Sight, had judged of Diſtances, Magnitudes, and Situations, it had been true that the optick Angles, formed that inſtant in his *Retina*, had been the immediate Cauſes of his Thoughts. Dr. *Barclay* accordingly has aſſured us, after Mr. *Locke*, (and indeed has gone beyond Mr. *Locke* in this Point) that neither Situation, Magnitude, Diſtance, nor Figure, would be at all diſcerned by a blind Perſon, at the Inſtant his Eyes ſhould receive Light.

Proof by an Experiment on a Perſon born blind, cured by Mr. Chiſelden.

But where was the blind Perſon to be found, on whom the indiſputable Deciſion of this Queſtion depended. In the Year 1729, Mr. *Chiſelden*, one of thoſe famous Surgeons, who unite a great Extent of

Knowledge with Dexterity in Operations, having imagined, that Sight might be given to a Perſon born blind, by removing the Cataracts, which he conceived to have been formed in his Eyes almoſt at the Moment of his Birth, he propoſed the Operation. The blind Perſon made Difficulties to conſent to it. He could not very well conceive, that the Senſe of Sight could contribute much to his Happineſs. Without inculcating to him the its uſe for learning to read and write, he had never deſired to ſee. His Indifference in this Point proves, that *It is impoſſible to be unhappy by the Privation of the Good of which we have no Idea.* A very important Truth. However that be, the Operation was performed and ſucceeded. The Youth then about fourteen Years of Age, ſaw the Light for the firſt Time. This Experiment confirmed all that *Locke* and *Barclay* had therein rightly foreſeen. For a long Time he diſtinguiſhed neither Magnitude, Diſtance, Situation, nor even Figure. An Object of an Inch placed before his Eyes, that concealed an Houſe from his Sight, appeared to him as big as the Houſe. Every Thing he ſaw, ſeemed at firſt to be upon his Eyes, and to touch them, as the Objects of the Senſe of Feeling touch the Skin. He could not diſtinguiſh what he had judged round, by the Help of his Hands, from what he had judged ſquare; nor diſcern with his Eyes, whether what his Hands had perceived to be above or below, were really above or below. He was ſo far from knowing Magnitudes, that after having at Length conceived by Sight, that his Houſe was larger than his Chamber, he could not conceive how Sight could give him that Idea. He could not perceive, till after two Months Experience, that Pictures only repreſented ſolid Bodies, and when, after ſo long a Trial of his new Senſe, he had thought, that Bodies, and not Surfaces only, were in the painted Tables, he applied his Hand to them, and was amazed that he did not feel thoſe ſolid Bodies, of which he began to perceive the Repreſentations. He aſked which of the Senſes deceived him, that of Feeling, or that of Seeing.

This was an indiſputable Deciſion, that the Manner in which we ſee Objects, is no immediate Conſequence of the Angles formed in our Eyes; for the ſame mathematical Angles were in the Eyes of this Youth, as well as in ours, and were of no Manner of Uſe to him without the Aid of Experience, and the other Senſes.

In what Manner we know Magnitudes and Diſtances.

In what Manner then do we repreſent Magnitudes and Diſtances to ourſelves? In the ſame as we imagine the Paſſions of Men, by the Colours which thoſe Paſſions paint in their Faces, and the Alteration they make in their Features. There is nobody who does not immediately read Shame or Anger in another's Countenance. This is the Language which Nature ſpeaks to every Eye; but a Language to be learnt only by Experience. It is Experience only that alſo teaches us, that when an Object is too remote, we ſee it confuſedly and faintly: From thence we form Ideas, with which the Senſation of Sight is ever after attended. Thus every Man, who, at the Diſtance of ten Paces, has ſeen a Horſe five Foot high, if he ſees, ſome Minutes after, the ſame Horſe no bigger than a Sheep, his Mind, by an involuntary Judgment, concludes immediately that the Horſe is a great Way off.

It is certain, that when I ſee my Horſe ſo ſmall as a ſmaller Image, a more acute Angle is formed in my Eye; but that is what attends, not what cauſes, my Thought.

This Angle is ſo far from being the immediate Cauſe that I judge an Horſe very far off when he ſeems very little; that every Moment I ſee the ſame Horſe of equal Size at ten, twenty, and thirty Paces from me, tho' the Angle is double, triple, and quadruple at thoſe different Diſtances.

In like Manner my Brain is affected differently, when I ſee a Man red with Shame, and when I ſee him red with Anger; but thoſe Impreſſions would ſuggeſt nothing to me of what paſſes in the Soul of that Man, without the Language of Experience, which alone imparts it to me.

Example.

I ſee a great Way off, through a little Hole, a Man upon the Top of a Houſe, the Diſtance and ſmall Number of Rays prevent me from diſtinguiſhing at firſt whether it be a Man or not: The Object ſeems very ſmall, and I take it for a Statue of two Feet at moſt: The Object moves, I conclude it a Man, and from that Inſtant he is thought to be of the uſual Stature; from whence proceed two Judgments ſo different?

When I believe I ſee a Statue, I imagine it two Feet high, becauſe I ſee it in ſuch an Angle: No Experience inclines my Thoughts to contradict the Rays impreſſed upon my *Retina**; but as ſoon as I judge it a Man, the Connection implanted in my Brain by Experience between the Idea of a Man and the Idea of an Height from five to ſix Feet, obliges me, without thinking of it, to imagine, by an inſtant Judgment, that I ſee a Man of ſuch a Height.

We learn to ſee as we learn to read.

From all this we muſt abſolutely conclude, that Diſtances, Magnitudes, and Situations, are not, properly ſpeaking, Things to be ſeen, that is to ſay, the proper and immediate Objects of Sight. The proper and immediate Object of Sight is nothing in Nature but coloured Light; all the reſt we only attain to know by Length of Time and Experience. We learn to ſee, exactly as we learn to ſpeak and read. The Difference is, that the Art of Seeing is the moſt eaſy, and that we are all equally Nature's Pupils in learning it.

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* Yes, the ſeeing it confuſedly and faintly, tells me its far off, and therefore bigger. *See* p. 66. l. 17.

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Extent not to be known from the Sight.

The ſudden and almoſt uniform Judgments, which every Mind forms at a certain Age of Diſtances, Magnitudes, and Situations, makes us think it only neceſſary to open the Eyes, in order to ſee Things as they are. But this is a Miſtake; the Aid of the other Senſes is eſſential to this Effect. If Men had no other Senſe but that of Sight, they would have no Means of knowing Extent, Length, Breadth, and Depth*; and a pure Spirit or Angel could never know it, unleſs God revealed it to him. It is very difficult to ſeparate in our Underſtanding the Extenſion of an Object from the Colours of it. We never ſee any Thing that is not extended, and from thence are all led into the Belief, that we actually ſee Extent. We can ſcarce diſtinguiſh in Thought the Yellow, which we ſee in a Piece of Gold, from the Piece of Gold of which we ſee the Yellow. Thus when we hear the Word a *Guinea* pronounced, we cannot help annexing the Idea of that Coin to the Sound we hear uttered.

If all Men ſpoke the ſame Language, we ſhould always be ready to believe, that there would be a neceſſary Connection between Words and Ideas. Now in this Point all Men have the ſame Language, with Reſpect to Imagination. Nature tells it to all that when you have ſeen Colours for a certain Time, your Imagination will repreſent to you, in the ſame Manner, all the Bodies, in which thoſe Colours ſeem inherent. That ſudden and involuntary Judgment, which you ſhall form, ſhall be uſeful to you during the Courſe of your Lives; for if, to judge of the Diſtances, Magnitudes, and Situations of all that ſurrounds you, it were neceſſary to wait till you had examined the Angles and Rays of Viſion, you would die before you knew, whether the Things you had Occaſion to uſe, were at the Diſtance of ten Paces from you, or at that of an hundred millions of Leagues, whether they were of the Bigneſs of a Mite or a Mouſe.

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* Except relatively, but not really without Feeling.

We are therefore very much in the wrong when we ſay our Senſes deceive us *. Each of them diſcharge the Function for which Nature intended them. They aſſiſt each other mutually, in conveying to the Soul by the

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* We ſuffer ourſelves to be directed by our Senſes.

Means of Experience, ſuch a Meaſure of Knowledge as our Condition admits. We demand of our Senſes, what they were not formed to beſtow. We are for knowing from our Eyes Solidity, Magnitude, Diſtance, *&c.* but the Touch muſt unite in this with the Sight, and Experience with both. If *Mallebranche* had conſidered Nature in this View, he had aſcribed fewer Errors to our Senſes, which are the ſole Springs of all our Ideas.

It is Time to reſume the Thread of *Newton*'s Diſcoveries, and to return to our phyſical and mathematical Enquiries.

CHAP. VII.

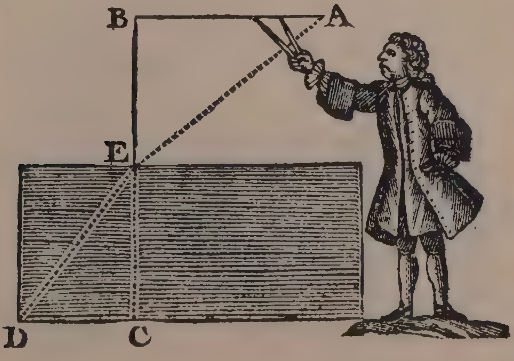
Of the Cauſe of the breaking of the Rays of Light in paſſing from one Medium to another; that this Cauſe is a general Law of Nature unknown before Newton; *that the Inflection of Light is alſo an Effect of the ſame Cauſe.*

WE have already ſeen the almoſt incomprehenſible manner, in which the Reflection of Light is performed, and which the known Impulſion cannot cauſe. That of Refraction, of which we are now going to reſume our Examination, is no leſs ſurprizing.

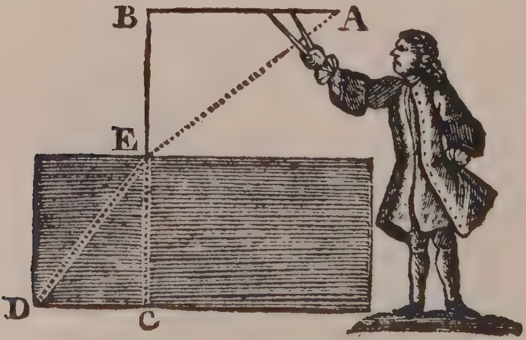
What Refraction is. Let us begin by eſtabliſhing in ourſelves a clear Idea of the Thing we are to explain. Let us remember well, that when Light falls from a more rare and thin Medium, as the Air, into one more heavy and denſe, as the Water, which in appearance ſhould reſiſt it more than the former, that then Light quits its Courſe or Direction, and breaks in a Line approaching to a perpendicular raiſed upon the Surface of that Water.

Mr. *Le Clerc*, in his Phyſicks, has ſaid directly the contrary for want of Attention. In the Eighth Chapter of his Fifth Book he ſays; " The greater the Reſiſtance of Bodies " is, the more the Light that falls into them " removes from a Perpendicular. Thus a " Ray removes from a Perpendicular in paſ- " ſing from the Air into Water." This is not the only Miſtake in *Le Clerc*, and a Man who ſhould have the Misfortune to ſtudy Phyſicks in the Writings of that Author, would ſcarce have any but falſe and confuſed Ideas.

To have a perfectly clear Idea of this Truth, obſerve the Ray A, E which falls from the Air into this Cryſtal.



You know in what manner it is broke. The Ray A E makes an Angle with the Perpendicular B E, in falling upon the Surface of the Cryſtal. The ſame Ray refracted in the Cryſtal makes another Angle with the ſame Perpendicular, which determines its Refraction. It was neceſſary to meaſure this Incidence and breaking of Light. *Snellius* firſt found the perpetual Proportion, according to which the Rays are broke in different Mediums. The Honour of it was aſcribed to *Deſcartes*. People always aſcribe to the Philoſopher of greateſt Reputation the Diſcoveries he publiſhes: he improves by the Labours of the obſcure, and augments his own Glory by their Enquiries. The Diſcovery of *Snellius* was a Maſter-piece in his Time. That Proportion is very intelligible.



The greater Line A B, which you ſee, is, the greater alſo will be the Line C D. The Line A B is called the *Sine* of Incidence. The Line C D is the *Sine* of Refraction. This is not a proper Place to explain in general what a *Sine* is. Thoſe who have ſtudied Geometry know it already. Thoſe who have not, might find ſome difficulty in the Definition of it. It ſuffices to underſtand aright, that theſe two *Sines*, of whatſoever Extent they be, are always in Proportion to one another according to the Medium.

The Light, which falls obliquely from the Air into the Cryſtal, is broke there in ſuch a manner, that the *Sine* of Refraction C D is to the *Sine* of Incidence A B, as 2 is to 3 *, which is no more than to ſay, that the A B is one third greater in the Air, in this Caſe, than the Line C D is in the Cryſtal.

In the Water this Proportion is from 3 to 4. Hence it is evident, that the Cryſtal refracts, or breaks, the Light one twelfth more ſtrongly than Water. Conſequently in all Caſes, and in all poſſible Obliquities of Incidence, Cryſtal will be more refracting than Water by a twelfth. The Queſtion is to know not only the cauſe of Refraction, but the cauſe of different Refractions.

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* This is true on Suppoſition that A E and E D were equal, then C D and A B would be Sines of the two Angles to one Radius.

Ingenious, but falſe Idea of Deſcartes.

Deſcartes, according to his Cuſtom, has invented ingenious and plauſible Reaſons for this Property of Light; but in this, as well as the reſt, ſetting his Wit in the Place of Reality, he has given us Conjectures inſtead of Truths. He tells us that Light, in paſſing from the Air into a new, more denſe, and compact Medium, paſſes more freely in it, and is leſs retarded in its pretended Tendency to Motion, and *leſs retarded*, ſays he, *leſs interrupted in a denſe Medium, as Glaſs, than in a thinner Medium, as Water.* We have already ſeen how much he impoſes upon himſelf in aſſerting, that Light has only a Tendency to Motion. We have ſeen, that the Rays actually move, becauſe they change their Place before our Eyes in their Refractions. But his Error here is ſtill farther important: He deceives himſelf in believing, that thoſe Bodies which break the Light moſt, are always the moſt ſolid, in which the Paſſage of Light is more eaſy. It is

The moſt ſolid Body does not refract moſt.

is not true, that all ſolid Bodies abſolutely refract Light more than fluid Bodies; for tho' in Effect Water does not occaſion ſo ſtrong a Refraction abſolutely ſpeaking, as Glaſs; however, in regard to its Denſity, it occaſions a ſtronger. It is certain that Light is broke a twelfth more in Glaſs than in Water; but if Refraction were determined in Proportion to Denſity, it ought much to exceed a twelfth in Glaſs. Imagine two Men, the one four times ſtronger than the other. If the ſtronger carry only a Weight twice as heavy as the weaker, we ſhould ſay with Truth, that in regard to his Strength, he does not carry ſo much as the other by a great deal; for he ought to carry four times as much. *Proof.*

Amber refracts much ſtronger in Proportion to its Denſity. Can one ſay however, that Amber opens a more eaſy Paſſage for Light than Cryſtal? It is therefore a falſe Suppoſition; *that Light is broken in a Line approaching to a Perpendicular, when it enters a more ſolid, tranſparent Body, which reſiſts it the leſs, becauſe it is more ſolid.*

Obſerve that every Experiment and Calculation deſtroys almoſt all the Ideas of *Deſcartes*, when that great Philoſopher founds them only upon Hypotheſes. They are ſhining and deluſive Proſpects, which diminiſh in Proportion as we approach them. All the reſt of the Philoſophers have endeavoured at Solutions of this Problem of Nature; but Experience has alſo refuted their Conjectures.

Miſtake of other great Philoſophers upon this Head.

Barrow taught, after Father *Deſchalles*, that the Refraction of Light, in approaching to a Perpendicular, was occaſioned *by the Reſiſtance of the Medium*; that *the more a Medium reſiſted the Paſſage of Light, the ſtronger that Refraction became.*

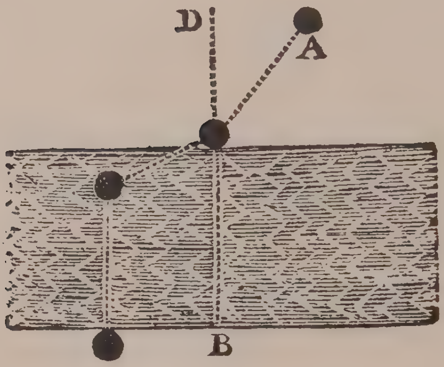
This Idea was the Reverſe of that of *Deſcartes*; and only proved, that there are different ways to Error. They had only to conſult Experiments; they had only to meaſure the Refractions made in Spirits of Wine, which are much greater than in Water; they had only to conſider, that Spirits of Wine undoubtedly do not reſiſt more than Water, and that however they occaſion a Refraction as ſtrong again; and they would then have corrected this ſmall Error. And indeed Father *Deſchalles* owns, that he very much ſuſpects his own Doctrine.

Newton's *great Diſcovery.*

At length *Newton* alone diſcovered the true Reaſon enquired after. His Diſcovery undoubtedly merits the Attention of all Ages. For the Queſtion here does not only regard a particular Property of Light, tho' that were a great Point; we ſhall ſee that this Property extends to all the Bodies in Nature.

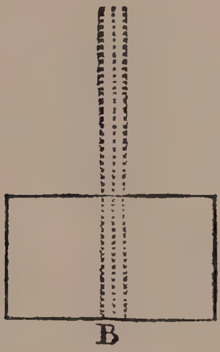
Conſider that the Rays of Light are in Motion, that if they turn aſide in changing their Courſe, it muſt be an Effect of ſome Primitive Law, and that, nothing ſhould happen to Light, but what ſhould happen to all other Bodies of the ſame ſmalneſs as Light, *cæteris paribus.*

Let a Ball of Lead A move obliquely from the Air into the Water, the contrary of what happened to the Ray of Light will happen to the Ball; for that a ſubtile Ray enters into the Pores of the Water, and the Ball, whoſe Superficies is large, encounters the Superficies of the Water which buoys it up.



This Ball removes then at firſt from the Perpendicular D B; but when it has entirely loſt the oblique Motion impreſſed upon it, it is left to itſelf, and falls directly in a perpendicular Line, from the Point where it began to ſink. Now *Newton* has diſcovered and proved, that there is a Power in Nature, which makes all Bodies tend towards each other in a ſtrait Line, in direct Proportion to their Quantity. This Power therefore (ſuch as it may be) muſt act in the Water upon a Ray, and the Quantity of the Ray being incomparably leſs than that of the Water, the Ray muſt be ſenſibly moved towards it.

Obſerve then this Ray of Light, which falls perpendicularly from the Air upon the Surface of this Cryſtal. As



As this Line falls perpendicularly, the Power of Attraction, ſuch as it is, acting in a right Line, the Ray does not turn aſide from its Courſe; but arrives more ſwiftly than it would have done in B; and this is another Truth diſcovered by *Newton.*

Before him, this Ray of Light was believed to be retarded in its Courſe by entring into the Water. On the contrary, it enters it with additional Force. But why? Becauſe it falls into it both by its own Motion, and by that which the Attraction of the Water, or the Glaſs, impreſſes upon it. This Ray arrives more ſwiftly in B, by this accelerative Force, than it would have paſſed through the Air without it.

But if we conſider in the ſame Baſon of Water, or the ſame piece of Glaſs, the oblique Ray which falls upon it, what follows? It retains its oblique Motion in a right Line, and acquires a new one in a perpendicular Line *.

That this Attraction, this Tendency, this kind of Gravitation exiſts, is not to be doubted: for we have ſeen Light, attracted by Glaſs, re-enter it without touching any Thing; now this Power neceſſarily acts in a perpendicular Line, that Line being the ſhorteſt way.

As this Power exiſts, it exiſts in all the Parts of Matter. The Parts of the Superficies of every Body whatſoever, do exert therefore this Power, before the Ray enters or attains the Center to which it is directed. Thus as ſoon as this Ray arrives near the Superficies of the Cryſtal or the Water, it begins to incline a little in this manner towards a Perpendicular.

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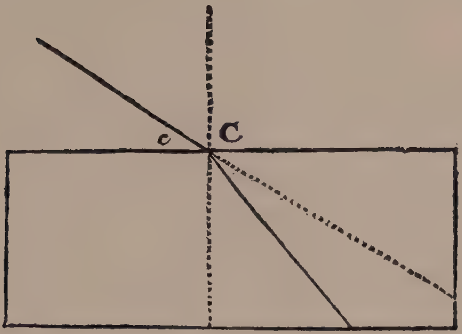
* Two Forces acting on it the ſame Time in different Directions, it takes a Courſe between them.



It begins to break a little in c, before it enters: the farther it goes, the more it breaks; that is, the nearer Bodies are the more they attract each other, and that which is more in Subſtance determines that which is leſs towards it. Thus the ſame happens to this Ray of Light as to every other Body that has two different Directions; it is engroſſed by neither, but holds a Courſe that participates of both. This Ray therefore neither falls entirely in a perpendicular Line, nor follows its firſt oblique Direction, in paſſing thro' the Water or the Glaſs; but it follows in a Line, which participates of both, and which deſcends the faſter, in Proportion to the Force with which the Water, or Cryſtal, attract it. The Water therefore, far from breaking the Rays of Light by reſiſting them, as was believed, really breaks them becauſe it does not reſiſt, and on the contrary becauſe it attracts them. We muſt therefore ſay, that the Rays are broken in a Line inclining towards a Perpendicular, not when they paſs from a more eaſy into a more reſiſting Medium, but when they paſs *from a leſs attracting, into a more attracting Medium.* Obſerve, that this Word *attracting* muſt never be underſtood, but as towards the Point to which that known Power, an indiſputable Property of Matter, directs itſelf.

You are ſenſible, that abundance of People, as much attached to the Philoſophy, or rather the Name, of *Deſcartes*, as they were formerly to the Name of *Ariſtotle*, have declared againſt Attraction. Some would not ſtudy it, others deſpiſed and condemned it, after having ſcarce examined it; but I beg the Reader to make the three following Reflections.

The Word Attraction ſhould be examined before declared againſt.

1. What are we to underſtand by Attraction? Nothing but a Force by which one Body approaches another, without any other Force being ſeen or known to impel.

2. This Property of Matter is received by the beſt Philoſophers in *England*, *Germany*, *Holland*, and even in many Univerſities of *Italy*, where Laws of a rigorous Nature ſometimes bar the Avenues to Truth. The Conſent of ſo many learned Men is no Proof indeed ; it is however a ſtrong Reaſon for examining at leaſt, whether this Power exiſts or not.

3. We ought to ſuppoſe, that we know no more of the Cauſe of Impulſion, than we do of that of Attraction. We even have not a greater Idea of the one than the other of theſe Powers; for no-body can conceive why a Body has Power by them to move another from its Place. Neither, indeed, do we conceive better why the Parts of Matter gravitate towards each other. *Newton* himſelf did not pretend to know the Reaſon of this Attraction. He has only proved its Exiſtence: he ſaw a conſtant Phænomenon, an univerſal Property in Matter. If a Man diſcovers a new Metal in the Earth, would this Metal exiſt the leſs, becauſe the firſt Principles of it were not known. Let the Reader of this little Treatiſe peruſe Mr. *Maupertius*'s Metaphyſical Diſcuſſion upon Attraction, in the

ſmalleſt and perhaps beſt wrote Philoſophical Book in *French.* He will there ſee thro' the Reſerve with which the Author explains himſelf, what he thinks, and what is to be thought of Attraction, of which the Name has given ſo much Offence.

We have ſeen in the ſecond Chapter, that the Rays of Light reflected to us from a Looking-Glaſs cannot be reflected from its Surface. We have ſeen experimentally, that the Rays, tranſmitted by a Glaſs to a certain Angle, return inſtead of paſſing into the Air; that, if there be a Void behind that Glaſs, the Rays which were tranſmitted before, return from that Void to us. In this Caſe there is certainly no Impulſion. Another Power muſt neceſſarily be admitted; and at the ſame time we muſt inevitably admit, that there is ſomething in Refraction hitherto not underſtood.

Now what Power is that, which breaks a Ray of Light in a Baſon of Water? It is demonſtrated, (as we ſhall ſhew in the following Chapter) that, what had hitherto been believed a ſingle Ray of Light, is a Groupe of many Rays, which are all differently refracted.

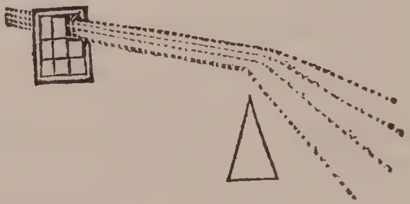
ed. If one of the Rays of Light contained in this Groupe is refracted, for Inſtance, at four Degrees diſtance, another will be at three, from a Perpendicular. It is demonſtrated, that the moſt refrangible, that is to ſay, thoſe which in being broke on quitting the Glaſs, and in taking a new Direction in the Air, go moſt from the Perpendicular of that Glaſs, are alſo thoſe which are reflected ſooneſt and with moſt Eaſe. It is therefore already very probable, that the ſame Law which occaſions the Reflection, occaſions alſo the Refraction of Light.

Proofs of Attraction.

Laſtly, If we find ſtill ſome new Property of Light, which appears to derive its Origin from the Force of Attraction, ought we not to conclude that ſo many Effects proceed from the ſame Cauſe?

This new Property was diſcovered by Father *Grimaldi* the Jeſuit about the Year 1660, upon which *Newton* has carried his Enquiries ſo far as to meaſure the Shadow of an Hair at different Diſtances. This Property is the Inflection of Light. The Rays not only break in paſſing the Medium, the Subſtance of which attracts them; but other Rays, which paſs in the Air near the Edges of the attracting Body, ſenſibly approach it, and viſibly turn aſide from their Courſe or Direction. Put a Blade of Steel or thin Glaſs ending in a Point, in a dark Place: let it be ſet near a little Hole through which the Light paſſes; and let the Light almoſt touch the Point of this piece of Steel or Glaſs.

Inflection of Light near Bodies that attract it.



The Rays will bend in ſuch a manner near it, that the Ray next the Point will be more curve, and the fartheſt from it leſs ſo in proportion. Is it not highly probable, that the ſame Power, which breaks theſe Rays, when in this Medium, forces them to incline towards it, and quit their Direction, when they are near it? Thus we ſee Refraction, Tranſparence, and Reflection ſubjected to new Laws; and an Inflection of Light reſulting evidently from Attraction. Thus a new Univerſe preſents itſelf to the Eyes of thoſe who are willing to ſee it.

We ſhall ſoon ſhew, that there is an evident Attraction between the Sun and the Planets, and a mutual Tendency of all Bodies towards each other. But we think proper to obſerve here, that this Attraction, which cauſes the Gravitation of the Planets towards the Sun, does not at all act in the ſame Ratio's, as the Attraction of Corpuſcles which touch each other. We muſt alſo remember well, that thoſe Ratio's change at the Point of Contact; and not believe, that Light is inflected towards the Cryſtal and in the Cryſtal in the ſame Ratio, for Inſtance, as Mars is attracted by the Sun. All Bodies, as we ſhall ſee, are attracted in the Ratio inverſe of the Squares of their Diſtances; but at the Point of Contact, they are attracted in the Ratio inverſe of the Cubes of their Diſtances, and even conſiderably more. Thus Attraction is much ſtronger, and the Force of it diſperſed with much greater Velocity; and this Attraction of Bodies, that touch each other, ſtill augments in Proportion to the ſmallneſs of the Bodies. Thus the Particles of Light, attracted by the ſmall Subſtance in Glaſs, are far from following the Laws of the Planetary Syſtem. Two Atoms, and two Planets, as Jupiter and Saturn, are governed by Attraction; but by different Laws of Attraction. This is what we ſhall explain in our laſt Chapter but one, and which we thought proper to premiſe here to remove all Ambiguity.

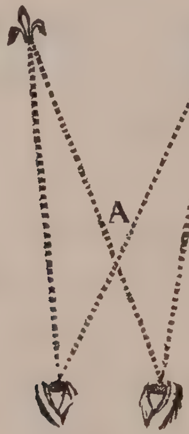
CHAP. VIII.

The wonderful Effects of the Refraction of Light. The ſeveral Rays of Light have all poſſible Colours in themſelves; what Refrangibility is. New Diſcoveries.

Imagination of **Deſcartes** *in reſpect to Colours.*

IF you aſk the Philoſophers what is the cauſe of Colours, *Deſcartes* will tell you, *That the Globules of his Elements are determined to turn round upon themſelves with Velocity, beſides their Tendency to Motion in a right Line, and that theſe different Whirlings round are the cauſe of different Colours.* But, in reality, what are his Elements, his Globules and Whirlings, do they require the Touchſtone of Experiment to prove them falſe? A multitude of Demonſtrations annihilate theſe Chimera's, of which the following are moſt ſimple and ſenſible.

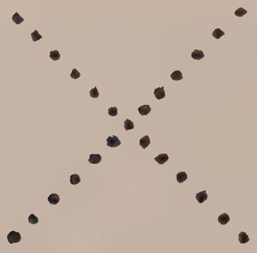
Diſpoſe a number of Balls againſt one another: ſuppoſe them puſhed and turning about with Velocity on all ſides, the very Words ſhew, that it is impoſſible for theſe contiguous Balls to move forward regularly in right Lines. Again in what manner ſhould we ſee this Point Blue and this Point Green upon a Wall?



Suppoſe them marked on this Wall; they muſt croſs each other at the Point A, before they reach our Eyes. As they croſs each other, their pretended Whirling muſt change at the Point of Interſection. The Whirlings of the Blue and the Green ſubſiſt then no longer as before; in Conſequence there would be no longer either the Point Green or the Point Blue. A *Flemiſh* Jeſuit made this Objection to *Deſcartes*. The latter was ſenſible of all its Force, but could one have imagined he would anſwer; *That thoſe Balls do not actually*

actually turn round, but that *they have a Tendency to turning round?* This *Deſcartes* ſays in his Letters. The Act of *tranſparent*, *quatenus tranſparent*, is it more intelligible?

You will tell me, without doubt, that there is the ſame Difficulty in all Syſtems: that the Rays from the Point Blue and the Point Green neceſſarily croſs each other, whatever Opinion we eſpouſe in reſpect to Colours; that this Interfection of the Rays muſt always prevent Viſion; in a Word, that it is always incomprehenſible, how Rays, which croſs each other, ſhould come to our Eyes in their proper Order; but this Scruple will ſoon be removed, if we conſider, that every Part of Matter has incomparably more Pores than Subſtance. A Ray of the Sun, thirty millions of Leagues in length, has probably not one Foot of ſolid Matter in its whole Extent. It would therefore be very poſſible for ſuch a Ray to paſs through another in this manner without diſplacing any thing.



They do not only paſs in this manner, but over one another like two Staffs. It may further be objected, that the Rays which flow from one Center, do not terminate exactly, and in Mathematical Strictneſs, at the ſame Point of the Circumference. That is true: and that Point muſt always be infinitely ſmall: but two Men never ſee the ſame Points of the ſame Object. This is alſo true. Of a thouſand millions of Perſons who ſhould look upon the ſame Superficies, no two of them would ſee the ſame Points.

In the *Plenum* of *Deſcartes*, it muſt be confeſſed, that this Interſection of the Rays is impoſſible; but every thing is equally impoſſible in a *Plenum*, and there is no Motion whatſoever that does not ſuppoſe and prove a *Vacuum*.

Error of Malle-branche.

Mallebranche in his turn tells us: *It is true* Deſcartes *deceived himſelf. His whirling of Globules is not to be maintained; but they are not Globules of Light, they are little Whirlings of ſubtile Matter, capable of Compreſſion, which are the cauſe of Colours; and Colours conſiſt like Sounds in the Vibrations of that Preſſion.* And he adds: *To me it ſeems impoſſible to diſcover by any Means the exact Proportions of theſe Vibrations*, that is to ſay, of Colours. It is remarkable, that he talks in this manner in the Academy of Sciences in 1699; and that theſe Proportions (or Ratio's) had already been diſcovered in 1675; not Proportions of little Whirlings which do not exiſt; but Proportions of the Refrangibility of the Rays, which forms Colours, as we ſhall preſently ſhew. What he believed impoſſible, was already demonſtrated, and what is more, demonſtrated to the Eyes, acknowledged true by the Senſes, which would have highly diſpleaſed Father *Mallebranche.*

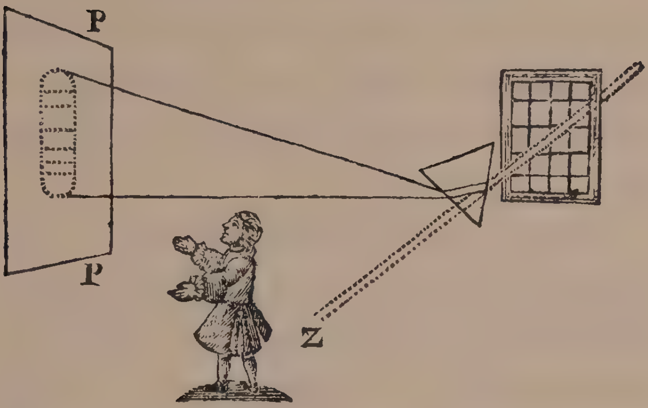
Other Philoſophers, perceiving the Fallacy of theſe Suppoſitions, tell us at leaſt with more Probability: *Colours are produced by the Rays of coloured Bodies more or leſs reflected.*

White reflects moſt, and Black leaſt of them all. The moſt ſhining Colours therefore are thoſe which emit moſt Rays to the Eye. Red, for inſtance, which pains the Sight a little, ought to conſiſt of more Rays than Green, which gives it moſt Eaſe. This Hypotheſis appears more rational at firſt; but is only Conjecture, (and that too very imperfect and erroneous) and a Conjecture is only a new Reaſon for enquiring, but not for believing.

Newton's *Experiments and Demonſtration.*

Let us apply to *Newton*. He will tell us; Don't believe me; believe only your Eyes, and the Mathematicks: place yourſelf in a Room entirely darkened, into which the Light comes only thro' an Hole exceedingly ſmall; the Ray of Light falling upon Paper will give you the Colour White.

Place a Priſm of Glaſs tranſverſally to a Ray of Light; then at the diſtance of about ſixteen or ſeventeen Feet fix the Sheet of Paper P, oppoſite to the Priſm.



You know already that Light is broke in entering the Priſm from the Air; you know that it breaks in a contrary manner in paſſing from the Priſm into the Air. If it was not broke it would fall from the Hole upon the Floor of the Room Z. But as this Light in paſſing from the Priſm muſt remove from the Line Z, it will in Conſequence ſtrike the Paper. There then appears the whole Secret of Light and Colours. The Ray, which falls upon the Priſm, is not, as was believed, a ſingle Ray, but a Group, conſiſting of ſeven principal Groups of Rays, each of which carries in itſelf a Primitive or Primordial Colour peculiar to itſelf *. From that Mixture of

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* It's hard to conceive how one Ray can be a Group or Bundle of Rays containing ſeven other Bundles; it's eaſier to conceive Rays of ſeven different kinds falling mixed on the Priſm that are afterwards ſeparated by it.

the ſeven Rays come all the Colours in Nature; and the whole ſeven united, and reflected together from one Object, form Whiteneſs.

Let us trace this admirable Artifice to the bottom. We have already inſinuated, that the Rays of Light are not all refracted or broken equally, of which this is an evident Demonſtration to the Eyes*. The ſeven Rays of Light having quitted the Body of the Ray, which is anatomized at paſſing from the Priſm, place themſelves each in its Order, upon the white Paper, each Ray occupying an Oval. The Ray which has leaſt Force, Rapidity, and Matter to keep its Direction, removes moſt in the Air from the Perpendicular of the Priſm. That which is the ſtrongeſt, moſt denſe, and moſt vigorous, removes leaſt from it. Obſerve theſe ſeven Rays, which are broke one above another.

Each of them paints upon the Paper the primitive Colour peculiar to itſelf. The firſt Ray, which removes leaſt from the Perpendicular of the Priſm, is the Colour of Fire;

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* There can be no Demonſtration to the Eye, not ſo much for that the Senſe is deceitful, as for that it's doubtful whence that Appearance flows.

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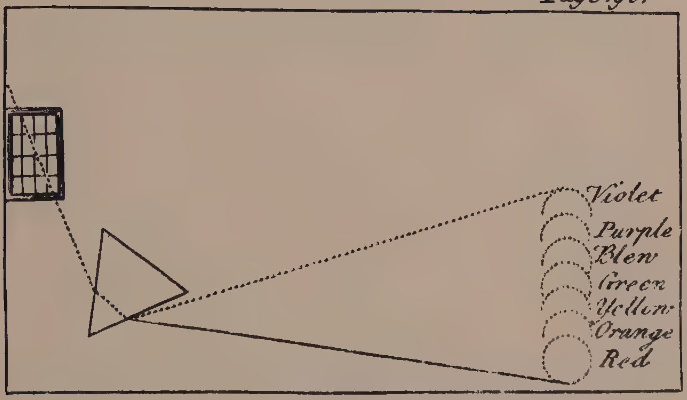
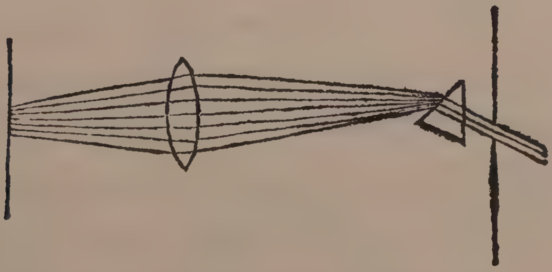


the ſecond orange; the third yellow; the fourth green; the fifth blue; the ſixth indigo; and the laſt, which removes moſt from the Perpendicular, and riſes above all the reſt, is the violet.

Anatomy of Light.

A ſingle Group of Light, which at firſt compoſed only Whiteneſs, is therefore one conſiſting of ſeven Groups of Rays, which have each their peculiar Colour. The aſſemblage of ſeven Primordial Rays therefore is what compoſes white.

If this be ſtill doubted, take a Lenticular Spectacle-Glaſs, which collects all the Rays at its Focus: place this Glaſs upon the Hole at which the Light enters, and you will never ſee any thing at the Focus but a round Spot of white. Place the ſame Glaſs at the Point, where it can collect all the ſeven Rays that paſs thro' the Priſm.



It unites, as you ſee, thoſe ſeven Rays in its Focus. The Colour of thoſe ſeven Rays is white; which demonſtrates that the Colour of all the Rays united is Whiteneſs. Conſequently the Body which reflects no Light will be black.

Colours in the primitive Rays.

For when by the help of the Priſm we have ſeparated ſome of theſe primitive Rays, tho' we make them fall upon a Looking-Glaſs, a Burning-Glaſs, or another Priſm, they will never change their Colour nor ſeparate into other Rays. To contain ſuch a Colour is their Eſſence, nothing can alter them more; and as a ſuper-abundant Proof, if we take Silk-Threads of different Colours, and lay one of them, a blue one for Inſtance at the red Ray, the blue Silk will become red. Put the ſame to the yellow Ray it becomes yellow; and ſo on with the reſt. In fine neither Refraction, Reflection, nor any other Means conceiveable can change this primitive Ray, being as unalterable, or rather more ſo, than Gold proved in the Crucible.

This Property of Light, this Inequality in the Refraction of its Rays, is what *Newton* calls Refrangibility. At firſt its Exiſtence was oppoſed, and continued to be denied a long time, becauſe Mr. *Mariote* had erred in making *Newton*'s Experiments in *France*. People were better pleaſed to ſay, that *Newton* had boaſted of having ſeen what he had not ſeen, than to think *Mariote* had not taken proper Methods for ſeeing the ſame, and had not been happy enough in the Choice of his Priſms. Even afterwards, when theſe Experiments had been well made, and Truth had ſhewn itſelf to our Eyes, Prejudice ſtill ſubſiſted to ſuch a Degree, that in ſeveral Journals and Books publiſhed ſince the Year 1730, the ſame Experiments are confidently denied, tho' made by all *Europe* every Day. In the ſame manner, after the Diſcovery of the Circulation of the Blood, Theſes were maintained againſt that Truth, and the Perſons who explained that new Diſcovery, nick-named *Circulators*, by way of Ridicule.

Vain Objections againſt theſe Diſcoveries.

At length, there are ſome who ſtill hold out when obliged to yield to Evidence: they have ſeen the Fact, but they cavil at the Expreſſion: they have declared War againſt the Term Refrangibility, as well as againſt thoſe of Attraction and Gravitation.

But, in the Name of Nonſenſe, what ſignifies the Term, provided it implies a Truth? When *Chriſtopher Columbus* diſcovered the Iſland *Hiſpaniola*, had he not a Right to call it by whatever Name he thought fit? And have not Inventors an equal Right to name what they create or diſcover? People have cried out and wrote againſt Words, which *Newton* has uſed with the wiſeſt Precaution to prevent Errors.

Criticiſms ſtill more abſurd.

He calls theſe Rays, red, yellow, *&c.* *rubrifick*, *flavifick* Rays, that is to ſay, exciting the Senſation of red, yellow, *&c.* His Intent in this was to ſtop the Mouths of thoſe, who ſhould have the Ignorance, or Injuſtice, to impute to him, that he believed with *Ariſtotle*, that Colours are in the things themſelves, in the yellow and red Rays, and not in our Mind. He had reaſon to apprehend this Accuſation. I have met with Perſons, and thoſe too of ſome Merit, who have aſſured me, that *Newton* was a Peripatetick, that he thought the Rays themſelves actually coloured, as Fire was formerly believed hot; but the ſame Criticks aſſured me alſo, that *Newton* was an Atheiſt. It is true, they had not read his Works, but they had heard them ſpoken of by others, who had wrote againſt his Experiments, without having ſeen them.

The gentleſt Treatment thoſe who wrote firſt againſt *Newton*, gave his Syſtem, was to ſay it was an Hypotheſis; but what is an Hypotheſis? A Suppoſition. And can Facts ſo often demonſtrated be juſtly called a Suppoſition? Is it thro' Self-Love, that People will abſolutely have the Honour of writing againſt a great Man? Ought they not rather to be better pleaſed with being his Diſciples than Opponents? Is it becauſe they are born in *France*, that they are aſhamed of receiving Truth at the Hands of an *Engliſhman?* Such a Thought would ill become a Philoſopher. Whoever thinks right, has no regard here to *French* or *Engliſh*; he that inſtructs us is our fellow Countryman.

CHAP. IX.

The Cauſe of Refrangibility; from which it appears that there are indiviſible Bodies in Nature.

THE Refrangibility, which we have now ſeen, being united to Refraction, muſt have its Source in the ſame Principle. The ſame Cauſe muſt preſide in ſetting all theſe Springs in Motion: this is the Order of Nature. All Vegetables are nouriſhed by the ſame Laws; all Animals have the ſame Principles of Life. Whatever happens to Bodies in Motion, the Laws of Motion are immutable. We have already ſeen, that the Reflection, Refraction, and Inflection of Light, are the Effects of a Power, which is not Impulſion (at leaſt known Impulſion:) this ſame Power ſhews itſelf in Refrangibility; the Rays, which diſperſe themſelves to different Diſtances, inform us, that the Medium, in which they paſs, acts unequally upon them. A Group of Rays is attracted into the Glaſs; but that Group is compoſed of Rays unequal in their Subſtance. Thoſe unequal Quantities therefore obey unequally the Power by which the Medium acts upon them. The more ſolid and compact a Ray of Light is, the more it muſt reſiſt that Power, the leſs it muſt turn aſide from its Courſe or Direction, and the leſs it muſt be refrangible. Theſe Experiments confirm it in all Mediums and Caſes. The red Ray is always that, which turns aſide leaſt from its Direction; and the violet, that which always turns aſide moſt. So the red Ray has always more Subſtance, is harder, and more ſhining, and tires the Sight more. The violet, which of all the coloured Rays eaſes the Sight moſt, is the moſt refrangible, and conſequently is compoſed of the fineſt, and leaſt gravitating Parts. We muſt not believe here, that Light having Weight, and that one Ray weighs more than another, are meer Conjectures, formed at a venture.

Difference between the Rays of Light.

Light has Weight.

Experiments made by the moſt learned and judicious Perſons, inform us, that many Bodies acquire Weight, after having imbibed Light for a conſiderable Length of Time. The Particles of Fire, which penetrate their

Subſtance, augment it. But ſhould theſe Experiments be called in queſtion; Fire is Matter; therefore it has Weight, and Light is nothing but Fire.

It is evident, that a white Ray * weighs all the Rays that compoſe it. Now ſuppoſe for a Moment, that all the Rays of a Group equally remove from one another, it is then evident, that the red Ray being ſeven Times leſs refrangible than the violet Ray, it ought to have ſeven Times more Subſtance, and ſeven Times more Weight, than the violet Ray. Thus the red Ray weighing as ſeven; the orange, we ſuppoſe here, as ſix; the yellow, as five; the green, as four; the blue, as three; the purple-indigo, as two; and the violet, as one: the total Amount of all theſe Weights being twenty-eight, and the white Ray including them all, the white Ray according to this Calculation, is demonſtrated to weigh twenty-eight times as much as the violet Ray †.

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* By the white Ray is meant a Bundle of the ſeven different Rays.

† If the violet Ray be alſo a Bundle of as many Rays, it's the fourth Part of the other.

We have already ſeen how prodigiouſly ſmall the Rays of Light muſt be, which, containing in them all Colours from the Sun, penetrate a Pore of a Diamond. Abundance of Rays enter that Pore, and unite near the interior Part of one of its Surfaces. Of this great number of Rays, that occupy ſo ſmall a Space, there is not any, that do not contain ſeven primordial Rays. Each of thoſe Rays is itſelf a Group of Rays tinged with its Colour. The red Ray is an Aſſemblage of a very great Number of red Rays. The violet is an Aſſemblage of violet Rays. If therefore this Group of violet Rays weighs eight and twenty times leſs than one of white Rays *, what muſt a ſingle one of them weigh?

Atoms of which Light is compoſed.

Let us conſider one of theſe ſingle Rays, that differs from one of another Colour; for Inſtance, the ſmalleſt of the red Rays differs in every thing from the ſmalleſt of the violet: The ſolid Parts of which it is compoſed, muſt be ſo many Atoms perfectly hard. And indeed, if Bodies were not compoſed of ſolid, hard, indiviſible Parts, that is to ſay, of real Atoms, how could the Species of Bodies continue eternally the ſame? How could ſo invariable a Difference be preſerved? Muſt not the Parts, that conſtitute their Eſſence, be ſufficiently hard, ſolid, and firm, to be always what they are? For how in the Texture of a ſingle Grain of Corn, would ſo many Grains of Corn be included, and nothing elſe, if the Configuration of its ſmall Parts were not always the ſame, and always ſolid and indiviſible: which implies nothing elſe but always undivided? In the Egg of a Fly there are Flies *ad infinitum*; but if thoſe ſmall Parts, which contain ſo many Flies, were not perfectly hard, they would certainly be broke in pieces againſt each other, thro' the rapid Motion in which every thing in Nature is. They would be broke ſo much the more, becauſe the ſmaller Bodies are, the more Surface they have in Proportion. However this Inconvenience does not happen: the Egg of a Fly always produces the Flies it contained; every Seed, from that of Gold to that of Muſtard, remains eternally the ſame. It is therefore to be believed, that all the

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* Not the Group but one Ray in it, for the Rays in the one are as many as in the other.

Atoms are the Principles of Bodies.

Seeds of things are compoſed of Atoms always undivided, of which the Subſtances of every Thing conſiſt; but it is not ſufficient to point out this great Truth, to which the Obſervation of the Rays of Light has led us; we muſt demonſtrate it, and prove in the ſtricteſt Manner, that Atoms phyſically indiviſible neceſſarily exiſt *; which is what we proceed to ſhew in the following Chapter.

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* He means not Atoms that have no Parts, but that the Parts are not ſeparable, as pag. 111. line 12.

CHAP. X.

Proofs that there are indiviſible Atoms, and that the ſimple Particles of Light are Atoms of that kind. Diſcoveries continued.

WE have already ſeen how extremely porous all Bodies are. Water itſelf, which is but nineteen times leſs heavy than Gold, paſſes however thro' its Pores, tho' the moſt ſolid of Metals. There is no Body, which has not incomparably more Pores than Matter: but let us ſuppoſe a Cube, if you pleaſe, which has as much apparent Matter as it has Pores: by this Suppoſition then it will actually have only half the Matter it appears to have *; but each Part of this Body being in the ſame Caſe, and loſing in like manner the half of itſelf, this Cube then, by this ſecond Operation, will be only the fourth Part of itſelf; in Conſequence it will have only the fourth Part of the Matter it ſeems to have. Dividing in this manner each Part of each Part, the eighth Part of the Matter

Proof of the Exiſtence of Atoms.

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* If the Matter be actually one half and the Pores the other half, the Matter hath no Pores, and there is an End of it.

Matter will remain. This Progreſſion continued *ad infinitum*, and the Diviſion carried on thro' all Degrees of Infinite, the End of the encreaſing of the Pores will be Infinity, and the End of the Diminution of Matter will be nothing. Therefore if Matter could be phyſically divided *ad infinitum*, it would be found, that there would be nothing but Pores and no Matter. Matter then, ſuch as it is, is not in reality phyſically diviſible *ad infinitum*: Therefore it is evident, that there are indiviſible Atoms, that is to ſay, Atoms which will never be divided, as long as the preſent Conſtitution of the World ſubſiſts.

Let us conſider this Demonſtration in a ſtill more palpable manner. I am come by my Diviſion to the two laſt Pores: there either is a Body between them, or there is not, if there is not, there was then no Matter; if there is, that Body is then without Pores. I ſay it is without Pores; becauſe I am come to the laſt Pores, this Particle of Matter is therefore actually indiviſible.

Moreover, this Propoſition ought not to appear contradictory to Geometrical Demonſtration, which proves a Line diviſible to Infinity.

These

The Diviſibility of Matter does not prevent the Exiſtence of Atoms.

Theſe two Propoſitions, which ſeem to deſtroy each other, agree very well together. Geometry has for its Object the Ideas of the Mind. A Geometrical Line is a Line in Idea, always diviſible in Idea, as a numerical Unity is always reducible into as many Unites as I think fit to conceive. I can divide the Unity of a Foot into an hundred thouſand millions of millions of other Unites; but then I can always conſider the ſame Foot as a ſingle * Unity.

Points without Lines, Lines without Superficies, Superficies without Solids, the Infinite 1, the Infinite 2, the Infinite 3, are in reality the Objects of certain Geometrical Propoſitions: but it is no leſs certain that Nature cannot produce Superficies, Lines, or Points, without Solids. It is no leſs indiſputable, that a Line in Geometry is diviſible to Infinity; it is alſo certain, that there are indiviſible Bodies in Nature, that is to ſay, undivided Bodies, Bodies which will remain ſuch, as long as the preſent Conſtitution of Things ſubſiſts.

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* Mr. *de Maleſieu*, in the Duke of *Burgundy*'s Geometry, has not ſufficiently conſidered this Truth, p. 117. He finds Contradiction where there is none. He asks as a Queſtion not to be ſolved, whether a Foot of Matter be one Subſtance, or many? It is certainly one Subſtance, when conſidered as a Cubick Foot. But it is ſeventeen hundred and twenty-eight Subſtances, when divided into Inches.

Let us hold therefore as certain, that there are Atoms. Each conſtituent Part of a ſimple coloured Ray, may be conſidered as an Atom; each of theſe Atoms is of Weight; it is the different Attraction, which cauſes the different Refraction. Let us conceive, that the moſt refrangible of theſe Atoms are alſo the moſt reflexible, and that as they are refracted in Proportion to their Attraction towards the moſt actuating Medium, it follows, that they are reflected in Proportion to the ſame Attraction. It is eaſy to know at this time, that the violet Ray, for Inſtance, which is the moſt refrangible, is always the firſt reflected on quitting the Priſm which has received all the Rays. *Newton* made this Experiment by the help of four Priſms, with a Sagacity and Induſtry worthy of the Diſcoverer of ſo many Truths,

I ſhall here give the moſt ſimple of his Experiments.

Important Experiments.

The Priſm has thrown the ſeven Colours upon the Paper: turn the Priſm upon itſelf in the manner A, B, C, and you will preſently have the Angle, according to which all Light will be reflected from the inſide to the outſide of the Priſm, inſtead of being thrown upon the Paper: as ſoon as you begin to approach that Angle, you ſee on a ſudden the violet Ray quit the Paper, and riſe to the Cieling. After the violet, the purple does the ſame, after the purple the blue; and ſo on, till the red quits its place upon the Paper laſt, and is reflected on the Cieling in its turn. Every Ray therefore is the more reflexible in proportion as it is more refrangible: in Conſequence the ſame Cauſe produces Reflection and Refraction.

Now the ſolid Part of the Glaſs occaſions neither this Refraction, nor this Reflection: once more then theſe Properties have their Riſe in ſome other Cauſe than the Impulſion, known to us upon the Earth. There is nothing to be ſaid againſt theſe Experiments; we muſt ſubmit to them however tenacious we are againſt Evidence.

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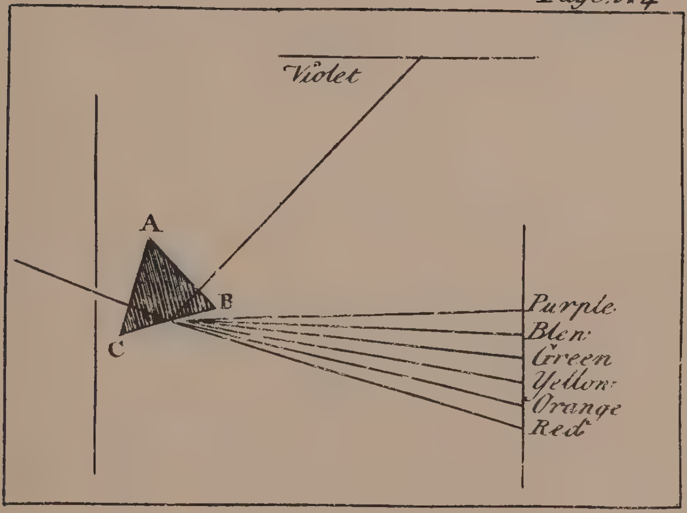


Matter might be taken even from *Newton*'s Experiments to form ſome Difficulties againſt the Laws he eſtabliſhes. One might tell *Objection.* him, for Inſtance: you have proved that no known Impulſion of Body can produce either the Refraction or Reflection of Light, becauſe it is refracted in Pores, and reflected in Void: you have told us, that there is a Power in Nature which makes all Bodies tend towards each other; and till you ſhew us, as you have promiſed, the Laws by which that Power acts, we conceive, that it muſt act in Effect upon all Matter, and that the ſmalleſt Bodies imaginable muſt be determined in the ſame manner by this Power, as the greateſt Bodies poſſible: you have told us, that one of the Laws of this Power is to act upon all Bodies according to their Quantity or Subſtance; and we confeſs that to be very probable; but do not your own Experiments contradict this Syſtem? Water has much more Solidity or Subſtance than Spirits of Wine, or Spirits of Turpentine; it however attracts the Rays of Light leſs; thoſe Rays are not ſo much refracted in Water as in Spirits of Wine; this Power of Gravitation and Attraction therefore does not act, as you tell us, according to Quantity or Subſtance.

Anſwer. Why Fluids of leſs Weight than Water attract Light more.

This Objection, far from making the Truth of the new Diſcoveries doubtful, really confirms it. To anſwer it clearly let us conſider, that all Bodies tend towards the Center of the Earth; that they all fall in the Air with a Force proportioned to their Maſs or Subſtance; but if beſides this Force another be applied to them, they will move with greater Velocity than they have from their own Weight. This is the Caſe of the Rays of Light when they enter Bodies already full of fiery Particles, which are nothing but Light itſelf retained in their Pores.

Theſe Atoms of Fire, which actually reſide in certain ſulphurous and tranſparent Bodies, encreaſe the Refraction of Light towards a perpendicular Line, as a new Force applied to it: it happens in this Caſe, as in that of a Torch juſt put out and ſtill ſmoaking; it will light again at a certain diſtance from another lighted Torch.

It is entirely as natural for the Rays of Light to enter with Eaſe into the ſulphurous Spirit of Turpentine, as for the Flame to catch the ſmoaking extinguiſhed Torch; now a new Cauſe added to Refraction neceſſarily augments it.

Beſides which Re-action is always equal to Action: Sulphurous Bodies are thoſe on which Fire, that is nothing but Light, acts with greateſt Force; thoſe Bodies therefore muſt alſo act upon, break and refract Light more than any other.

Attraction does not extend to all the Effects of Light.

Let us here obſerve, that this Attraction inherent in Matter, does not extend univerſally, and produce all Effects. The Myſtery of Light reflected from the midſt of Pores, and from above Surfaces without touching them, has Depths which the Laws of Attraction cannot fathom: only Quacks boaſt of Univerſal Medicines; and he would be a Quack in Philoſophy, who ſhould refer every thing without Proof to the ſame Courſe: the ſame Force of Mind, which enabled *Newton* to diſcover the Power of Attraction, made him confeſs that that Power was far from being the ſole Agent of Nature.

It is true, that the moſt refrangible Ray being the moſt reflexible, is an evident Proof, that the ſame Power operates the Reflection, Refraction, and Acceleration of the Rays in the Glaſs, *&c.* but however, the Force of Attraction ſeems to have nothing in common with other Phænomena. There are eſpecially Vibrations of Rays, alternative Dartings of Light, backwards and forwards over Bodies, which could not be explained by Gravitation; but theſe new Difficulties *Newton* himſelf did make. He has not only diſcovered the Myſteries, which Gravitation reveals, but others, which it does not reveal. Theſe alternative Dartings of the Reflection of Light, are one of the Secrets of Nature, which, it is aſtoniſhing, human Eyes have ever been able to perceive.

We ſhall ſpeak of this Singularity in its Place in the thirteenth Chapter; let us continue our view of the Effects of Refrangibility. The Rainbow is one, and the moſt conſiderable of its Effects, which we proceed to explain in the following Chapter.

CHAP. XI.

Of the Rainbow; that Phænomenon a neceſſary Effect of the Laws of Refrangibility.

Mechaniſm of the Rainbow entirely unknown to the Ancients.

THE Rainbow, or Iris, is a neceſſary Effect of the Properties of Light, of which we have juſt been ſpeaking. There is nothing in the Writings of the *Greeks*, *Romans*, or *Arabians*, that gives us reaſon to believe, they knew the cauſe of this Phænomenon. *Lucretius* ſays nothing of it, and by all the Abſurdities, which he vents in the Name of *Epicurus* upon Light and Viſion, it appears, that his Age, ſo polite in other Reſpects, was profoundly ignorant in Point of Phyſicks. They knew, that to ſee what we call the Rainbow, or Iris, a thick Cloud is neceſſary, diſſolving in Rain before the Rays of the Sun; and that our Eyes ſhould be between that Star and the Cloud, *Mille trahit varios adverſo ſole Colores*, but this was all they knew; no-body imagined either why a Cloud exhibited Colours, how the Nature and Order of thoſe Colours are determined, or wherefore we always ſee that Phænomenon under the Form of a Semi-circle.

Albertus, ſurnamed *Magnus the Great*, becauſe he lived in an Age wherein Men were very little, imagined that the Colours of the Rainbow proceeded from a Dew between us and the Cloud, and that thoſe Colours received upon the Cloud, were tranſmitted by it to us. You will obſerve beſides, that this *Albertus Magnus* believed, with all the Schools, that Light was an Accident.

The Archbiſhop Antonio de Dominis *was the firſt, who explained the Rainbow.*

At length the celebrated *Antonio de Dominis*, Archbiſhop of *Spalatro* in *Dalmatia*, expelled from his Biſhoprick by the Inquiſition, about the Year 1590, wrote his little Treatiſe, *De Radiis Lucis & de Iride*, which was not printed at *Venice* till twenty Years after. He was the firſt who ſhewed, that the Rays of the Sun, reflected even from the inner Part of Drops of Rain, formed thoſe Colours, that appeared in the Bow, which ſeemed an inexplicable Miracle; he rendered the Miracle Natural, or rather he explained it by new Prodigies of Nature.

His Diſcovery was ſo much the more ſingular, as in other Reſpects he had very falſe Notions of the manner in which Viſion is performed. He aſſures us in his Book, that the Images of Objects are in the Ball of the Eye, and that there is no Refraction in it: a Notion ſingular enough for a good Philoſopher! He had diſcovered Refractions, unknown before, in the Drops of the Rainbow, and denied thoſe operated in the Humours of the Eye, of which himſelf began the Demonſtration; but let us leave his Errors to examine the Truth he diſcovered.

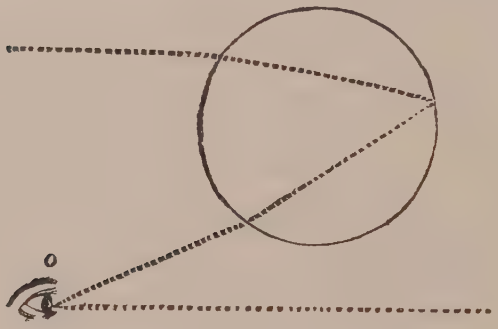
He ſaw with a Sagacity very uncommon in thoſe Days, that every Row or Circle of Drops of Rain, that form the Rainbow, muſt tranſmit the Rays of Light in different Angles, he alſo ſaw, that the difference of thoſe Angles muſt occaſion that of the Colours: he found means to meaſure the Magnitude of thoſe Angles: he took a very tranſparent Cryſtal Ball which he filled with Water, and hung up at a certain Height expoſed to the Rays of the Sun.

His Experiment.

Deſcartes, who followed *Antonio de Dominis*, and rectified and ſurpaſſed him in ſome things,

Imitated by Deſcartes.

things, and who perhaps ought to have quoted him, made alſo the ſame Experiment. When this Ball is ſuſpended at ſuch an Height, that the Ray of Light, which falls from the Sun upon the Ball, makes an Angle with the Ray, that falls from the Ball to the Eye, of forty two Degrees two or three Minutes, the Ball always exhibits a red Colour.



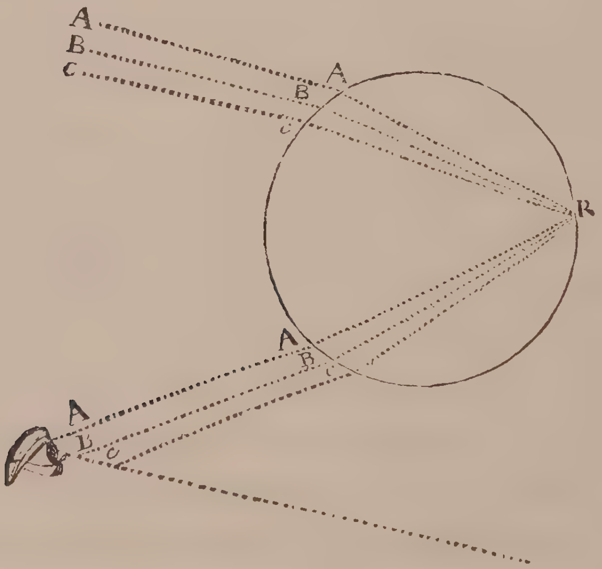
When that Ball is ſuſpended a little lower, and thoſe Angles are ſmaller, the other Colours of the Rainbow appear ſucceſſively in ſuch a manner, that the greateſt Angle in this Caſe forms the red, and the ſmalleſt of forty Degrees ſeventeen Minutes forms the violet. This is the Foundation of the Knowledge of the Rainbow; but at the ſame time it is only the Foundation of it.

Refrangibility the ſole Cauſe of the Rainbow.

Refrangibility alone explains a Phænomenon ſo common, ſo little known, and of which few Beginners have a clear Idea: let us endeavour to render the thing obvious to all the World. Let us ſuſpend a Ball of Cryſtal full of Water, expoſed to the Sun: let us place ourſelves between the Sun and it; wherefore does this Ball tranſmit Colours to me, and wherefore particular Colours? Great quantities of Light, millions of Groups of Rays, fall from the Sun upon this Ball: in each of thoſe Groups there are primitive Rays, homogeneous Rays, many red, many yellow, many green, *&c.* all which break at their Incidence into the Ball, each differently and according to its Species, and the Place in which it enters.

You already know that the red Rays are the leaſt refrangible; the red Rays of a certain determinate Group will therefore unite at a certain determinate Point at the bottom of the Ball, whilſt the blue and purple Rays of the ſame Group will do the ſame elſewhere. Theſe red Rays will alſo quit the Ball at one place, and the green, blue, and purple at another. This is not enough. We muſt examine the Points, where thoſe red Rays fall in entring the Ball, and in quitting it to come to the Eye.

To make this as clear as poſſible, let us conceive this Ball, as it really is, an Aſſemblage of an infinite Number of plane Superficies; for the Circle being compoſed of Right-points infinitely ſmall, the Ball is only an Infinity of ſuch Superficies.



The red Rays A, B, C, fall parallel from the Sun upon thoſe three ſmall Superficies. Is it not true that each of them breaks according to its Degree of Incidence? Is it not manifeſt that the red Ray A, falls more obliquely upon its little Superficies, than the red Ray B doth? Thus both come to the Point R, by different Ways or Directions.

The red Ray C, falling upon its little Superficies ſtill leſs obliquely than the two former, is much leſs broke, and arrives alſo at the Point R, with very little Incurvation.

That Phænomenon explained.

I have now three red Rays, that is to ſay, three Groups of red Rays, which terminate at the ſame Point R.

At this Point R, each of them makes an Angle of Reflection equal to its Angle of Incidence, each is broke at emerging from the Ball in a Line removing from the Perpendicular of the new little Superficies it comes to, in the ſame manner as each is broke at its Incidence in Lines, approaching each other, to their Perpendiculars; all therefore return parallel, and enter the Eye according to the opening of the Angle peculiar to the red Rays.

If there be a ſufficient quantity of theſe homogeneous red Rays to move the optick Nerve, we muſt indiſputably have the ſenſation of red.

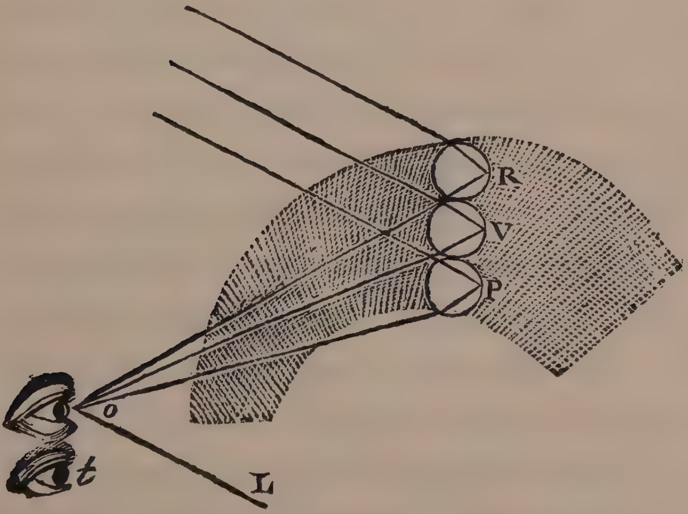
Theſe Rays A, B, C, are termed the viſible and operative Rays of the Drop of Rain; for each Drop has its viſible Rays.

There are thouſands of other red Rays, which falling upon other little Superficies of the Ball, higher and lower, or which falling on the ſame Superficies at another Obliquity, do not terminate in R; theſe are loſt to you, but will be ſeen by other Eyes placed higher or lower.

Abundance of orange, green, blue and violet Rays have fallen indeed with the viſible red ones upon the Superficies A, B, C; but you cannot receive them. You know the reaſon, which is their being all more refrangible than the red Rays: it is becauſe in entering all at the ſame Point, each of them takes a different Path in the Ball; as they are all more broken, they come below the Point R, and break alſo more than the red ones in quitting the Ball. The ſame Power, which in the inſide of the Ball made them approach in a Line more remote from the Perpendicular of each Superficies, diſperſes them therefore more at their return into the Air: they all return therefore above the Eye; but lower the Ball, and the Angle becomes leſs. Let this Angle be of forty Degrees and about ſeventeen Minutes, and you will ſee no Colour but the violet.

There is no-body who upon this Principle may not eaſily conceive the Doctrine of the Rainbow; imagine ſeveral Rows or Circles of Drops of Rain; every Drop has the ſame Effect as this Ball.

Caſt your Eye upon the Bow R, V, P, and to avoid Confuſion, conſider only three Rows of Rain-drops, three coloured Circles.



It is viſible that the Angle P, o, L, is leſs than the Angle V, o, L, and that the Angle R, o, L, is the greateſt of the three. The greateſt Angle of the three is therefore that of the red primordial Rays: that in the middle is that of the primitive green; and the leaſt P, o, L, is that of the primitive purple. We therefore muſt ſee the Rainbow red on its external, green on its middle, and purple and violet on its internal Circles. Obſerve only, that the laſt Circle, the violet, is always tinged with the whitiſh Colour of the Cloud in which it loſes itſelf.

It is eaſy to conceive then, that we ſee the Drops only in the operative or viſible Rays, which come to the Eye after one Reflection and two Refractions in determinate Angles. If we change the place of the Eye, and inſtead of being in o, bring it to t, we ſee the ſame Rays no longer: the Circle which before was red is now become orange or green, and ſo on with the reſt: at every Motion of the Head you ſee a new Iris.

This firſt Rainbow being well underſtood, we ſhall eaſily comprehend the ſecond, which is generally ſeen encircling the firſt, and which is called the falſe Rainbow, or *faint Bow*, be-

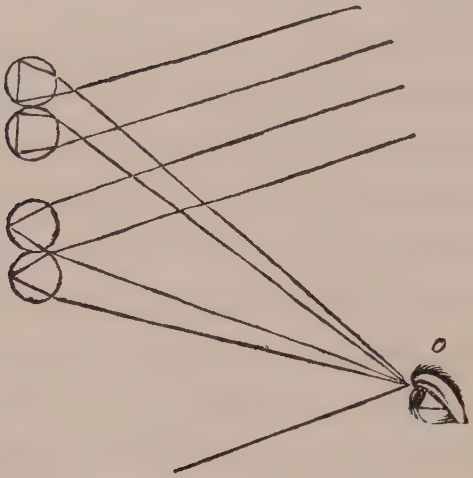
becauſe its Colours are not ſo lively, and are reverſed in their order to thoſe of the other.

Two Rainbows.

For the Appearance of two Rainbows, it ſuffices that the Cloud which forms them be ſufficiently thick and extended. That Bow which appears above the firſt and ſurrounds it, is formed in like manner by the Rays, which the Sun darts into the Rain-drops, and which are broken and reflected in them in ſuch a manner, that each Row of Drops tranſmits alſo primitive Rays to the Eye; this Drop a red, and that a violet Ray.

But every thing in this great Bow is the reverſe of what paſſes in the ſmaller; how comes that? It is becauſe your Eye, that receives the ſenſible or operative Rays of the ſmaller Bow, which fall from the Sun into the upper Part of the Drops, receives on the contrary the Rays of the greater Bow from the lower part of the Drops.

You perceive, that the Drops of Water of the ſmaller Bow receive the Rays of the Sun upon the upper part of each Drop; the Drops of the greater Bow on the contrary receive the Rays, that reach them, on their lower part. Nothing in my Opinion will be



more eaſy to conceive, than the manner in which the Rays are twice reflected in the Drops of the great Rainbow, and how thoſe Rays twice refracted and twice reflected exhibit an Iris reverſed in the order of its Colours, and fainter than the former. You have juſt ſeen that the Rays enter thus into the little lower Part of the Drops of Water of this exteriour Iris.

A number of Rays fall on the Superficies of the Drop in G, a part of thoſe Rays are refracted there within, and another ſcattered without; thus the Eye has already loſt part of thoſe Rays. The Part refracted comes to

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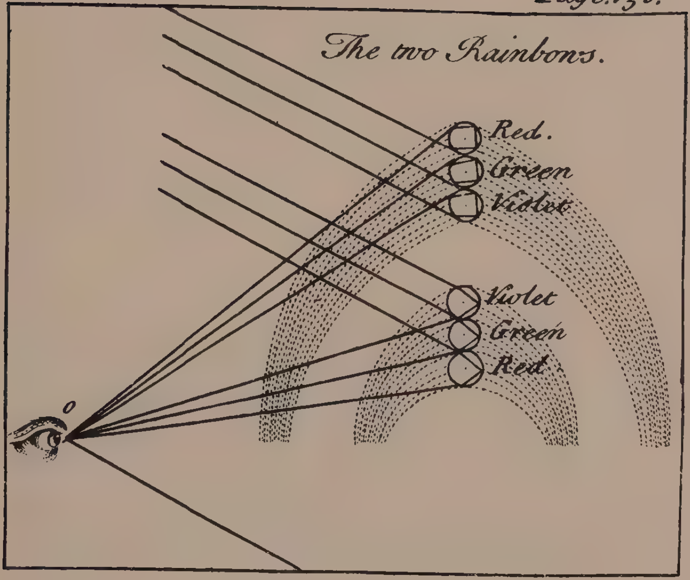
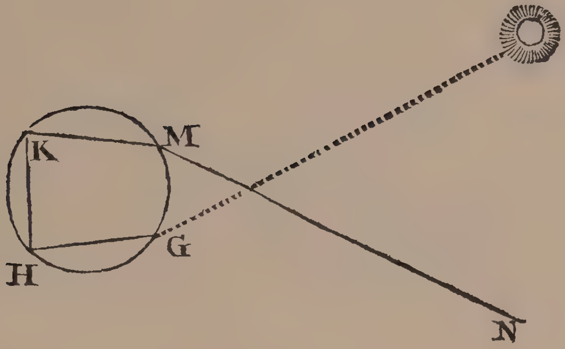


The two Rainbows.



H, one half of this Part is diſperſed in the Air on quitting the Drop, and is again loſt to the Eye. The little that remains in the Drop is tranſmitted to K, there a Part of it eſcapes again: this is a third Diminution. What has remained of it in K is transferred to M, and on this Emergence to M, a Part of it is again diſſipated: fourth Diminution; and what remains comes to the Eye at laſt in the Line M, N. Thus therefore we ſee in this Drop as many Refractions as in the Drops of the ſmaller Bow; but there are, as we have ſhewn, two Reflections inſtead of one in this greater Bow. Twice the Light therefore is loſt in the greater Bow, in which the Light is twice reflected, whilſt leſs by one half is loſt in the ſmaller Bow, where the

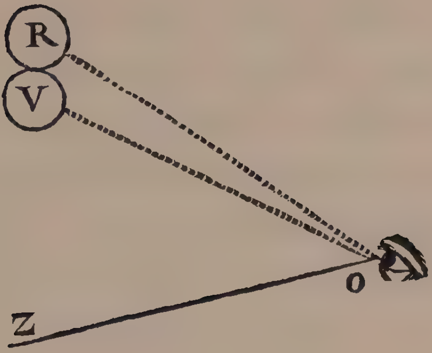
Drops are once reflected. It is therefore demonſtrated, that the exteriour Rainbow muſt always be fainter by one half in its Colour than the ſmaller within it. It is alſo demonſtrated by the double Reflection of the Rays, that they muſt come to the Eye in a manner oppoſite to that of the firſt Bow, for your Eye is placed in O.

In this place O, it receives the leaſt refrangible Rays of the firſt exteriour Circle of the ſmaller Bow, and muſt receive the moſt refrangible of the firſt Circle of the ſecond greater Bow; theſe moſt refrangible Rays are the violet. Thus then we have here the two Rainbows in their natural Order, giving them only three Colours to avoid Confuſion.

This Phænomenon always ſeen in a Semi-circular Figure.

It only remains for us to know wherefore thoſe Colours are always perceived in a circular Figure. Conſider this Line O, Z, which paſſes thro' your Eye. Conceive the two Balls R, V, to move always at equal Diſtances from your Eye; they will deſcribe the Baſes of Cones, of which the Points will always be in your Eye.

Con-



Conceive that the Ray of the Drop of Water R, coming to your Eye o, turns round this Line o, Z, as round an Axis, making always an Angle with your Eye of forty-two Degrees two Minutes; it is plain this Drop will deſcribe a Circle, which will appear red. Suppoſe the other Drop V, to turn in the ſame manner, making always another Angle of forty Degrees ſeventeen Minutes, it will form violet Circle; all the Drops therefore in this Plan will form a violet Circle, as thoſe in the Plan of the Drop R, will a red one. We ſee therefore this Iris as a Circle, but not as an entire Circle; becauſe the Earth cuts it, we ſee only an Arch, the Section of a Circle.

Neither *Antonio de Dominis* nor *Deſcartes* could penetrate any farther into moſt of theſe

Truths: they could not diſcern wherefore theſe different Angles exhibited different Colours; but it was a great deal to have diſcovered the Art. The Perfection of Arts are ſeldom owing to the firſt Inventors. Not being able therefore to gueſs that Colours depended on the Refrangibility of Rays, that each Ray contained a primitive Colour in itſelf, that the different Attraction of thoſe Rays was the cauſe of their different Refrangibility, and occaſioned thoſe Removals which formed the different Angles, *Deſcartes* abandoned himſelf to his Spirit of Invention to explain the Colours of the Rainbow. In order to this he employed the imaginary *whirling round of Globules* and his *Tendency to whirling round*; Proofs of Genius, but Proofs of Error. Thus to explain the *Syſtole* and *Diaſtole* of the Heart, he imagined a Motion and Conformation of that Organ, of which all Anatomiſts have admitted the Falſity. *Deſcartes* would have been the greateſt Philoſopher of the World, if he had invented leſs.

CHAP. XII.

New Diſcoveries touching the Cauſe of Colours, which confirm the preceding Doctrine, Demonſtration that Colours are occaſioned by the Denſity *and Thickneſs of the Parts of which Bodies are compoſed* *.

IT reſults then, from what has hitherto been ſaid, that all Colours proceed from the Mixture of the ſeven primitive ones, of which the Rainbow and the Priſm give us a diſtinct View.

The Bodies that are moſt proper to reflect the red Rays, and whoſe Parts either abſorb or tranſmit the other Rays, will be red; and in like manner of the reſt. The Meaning of this is not, that the red Rays are actually reflected by the Parts of theſe Bodies; but that there is a Power, a Force hitherto unknown, which reflects theſe Rays from about the Surfaces of Bodies, and the Cavity of their Pores.

Colours then are in the Rays of the Sun, and

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* Or as in pag. 137, line 2, the Thickneſs of the Parts that compoſe the Surfaces only, and pag. 138, line 15, and pag. 140, line 13.

A more minute Inquiry concerning the Formation of Colours.

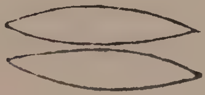
and return to us from the Surfaces and Pores of Bodies, and from the Vacuum. Let us now enquire in what the apparent Power of Bodies to reflect theſe Colours conſiſts, what occaſions Scarlet to appear red, why the Meadows are green, and why a clear Heaven is blue: For to ſay that this proceeds from the Difference of the Form of their Parts, is to advance an indeterminate Notion, that makes us never the wiſer.

Great Truths drawn from a common Experiment.

A childiſh Diverſion, that ſeems to have nothing in it but what is contemptible, gave Sir *Iſaac Newton* the firſt Idea of theſe recent Truths which we are now to explain. Every Thing to a Philoſopher may be a Subject of Meditation, and nothing is deſpicable in his Eyes. He perceived, that in thoſe Bubbles of Soap and Water that are blown up by Children, the Colours changed every Moment, paſſing downwards ſucceſſively from the Top of the Bubble, in proportion as the Thickneſs of it diminiſhed, till at laſt the Weight of the Water and Soap, which ſtill fall to the Bottom, breaks the Equilibre of that light Sphere, and cauſes it to vaniſh. He preſumed from hence, that Colours might probably depend on the Thickneſs of the Parts that compoſed the Surfaces of Bodies; and to aſſure himſelf of it, he had recourſe to the following Experiments *.

An Experiment of Sir Iſaac.

Let two Glaſſes touch one another in a ſingle Point. They need not be both convex; it is ſufficient that the firſt is ſo, and that it be placed upon the other in this manner.



Let Water be put between theſe two Glaſſes, to render more ſenſible the Experiment which is made at the ſame Time in the Air. When the Glaſſes are preſſed a little againſt each other, a ſmall, tranſparent, black Spot appears at the Point of their Contact. From this Point, ſurrounded with a little Water, coloured Circles form themſelves, in the ſame Order and Manner as in the Bubble of diluted Soap. In a Word, by meaſuring the Diameter of theſe Circles, and the Convexity of the Glaſs, Sir *Iſaac Newton* determined the different Thickneſs of the

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* There ſeems to be a difference between the Parts of Gold or Scarlet Cloth, and Bubbles of Water that are hollow and tranſparent.

Portions of Water which gave theſe different Colours. In particular, to reflect white Rays, he found that the Thickneſs requiſite, was about the 250,000th Part of an Inch, that is, about four ſuch Parts of an Inch as the Diviſion of it into a Million would produce. The azure Blue, and the Colours bordering upon a Violet, depend on a Thickneſs yet much leſs. Thus the pureſt Vapours which ariſe from the Earth, and which colour the Air without clouding it, being of a very thin Surface, produce that celeſtial Blue which charms our Sight.

Colours depend on the Thickneſs of the Parts of Bodies, notwithſtanding that theſe Parts reflect not the Light themſelves.

This Diſcovery, that Colours are attached to the Thickneſs of Surfaces, has been ſupported by other Experiments, no leſs curious than what we have now mentioned.

The ſame Body that was green, when it was ſomewhat thick, has become blue, when it has been rendered thin enough to reflect nothing but blue Rays, and to tranſmit all the others. Theſe Truths, of ſo delicate a Reſearch, and which ſeem to withdraw themſelves from human Sight, deſerve well to be cloſely purſued: This Part of Philoſophy is by a Microſcope, with which the Mind diſcovers Magnitudes infinitely ſmall *.

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* But not the Atoms in the Rays of Light.

All Bodies are tranſparent.

All Bodies are tranſparent; we have only to reduce them to a proper Tenuity, and then the Rays of Light, finding but a thin Plate, but a Leaf to paſs thro', make their Paſſage accordingly. Thus when a Leaf of Gold is placed againſt a ſingle Hole in a dark Room, it reflects from its Surface the yellow Rays, which cannot paſs thro' its Subſtance, and tranſmits green Rays into the Room; ſo that Gold then produces a green Colour. This is a farther Confirmation of what was before advanced, that Colours depend on the Difference of Denſities.

A Proof that Colours depend on Thickneſſes.

A yet ſtronger Proof of the ſame thing, is in the Experiment of the two Glaſſes, which are made to touch in a convex Point: The Water here is not the only Element that produces different Colours according to its different Denſities; the Air produces the ſame Effect, only the coloured Circles that it makes between the two Glaſſes, have a larger Diameter than thoſe of the Water.

There is a ſecret Proportion therefore, eſtabliſhed by Nature, between the Force of the conſtituent Parts of all Bodies, and the primitive Rays which colour thoſe Bodies: The thinneſt Bodies give the moſt feeble Colours, and to reflect a Black, the ſame Thickneſs, or rather the ſame Tenuity, the ſame Thinneſs is requiſite, as that which conſtitutes the very Top of a Bubble of diluted Soap, in which a little black Spot is perceived; or even the ſame as is in the Point of Contact between the convex and the flat Glaſs, which Contact produces alſo a black Spot.

And that neverthe-leſs, the ſolid Parts do not re-flect the Light.

But once more; It muſt not be imagined that Bodies reflect the Light by their ſolid Parts, becauſe we have ſhewn that Colours depend on the Denſity of theſe Parts: There is a Power attached to that Denſity, a Power that acts near the Surface; yet it is not in the leaſt the ſolid Surface, that repells, that reflects. This Truth ſhall be more ſenſibly demonſtrated in the following Chapter, than it has hitherto been. It ſeems to me, that the Reader ſhould by this Time be arrived at a Point, where nothing ought to ſurpriſe him for the future: But what he has juſt been ſeeing will lead him farther than he may imagine; ſo many Singularities being, if we may uſe the Expreſſion, but the Frontiers of a new World.

CHAP.

CHAP. XIII.

Conſequences of theſe Diſcoveries. The mutual Action of Bodies upon Light.

THE Reflection of Light, its Inflection, its Refraction, its Refrangibility being known, the Origin of Colours being diſcovered, and even the neceſſary Thickneſs of Bodies to occaſion certain Colours being determined; it remains that we ſhould examine two more Properties of Light, not leſs new, nor leſs ſurpriſing than the reſt. The firſt of theſe Properties is that Power itſelf which acts near the Surfaces of Bodies, and which is a mutual Action of the Light upon Bodies, and of Bodies upon the Light. The ſecond is a Reſemblance which is found between Colours and the Notes in Muſick, between the Objects of the Sight and thoſe of the Hearing. We proceed to render an Account of theſe two miraculous Qualities: and with this Account we ſhall finiſh our Introduction to Sir *Iſaac Newton*'s Opticks.

A very ſingular Experiment.

You have ſeen that two Glaſſes, touching one another in a Point, produce Circles or Rings of different Colours, as red, blue, green, white, *&c.* Make the Trial of theſe Glaſſes in your dark Room, where you made the Experiment of the Priſm expoſed to the Light that comes in on it through a Hole. You remember, that in this Experiment of the Priſm you ſaw the Decompoſition of Light, and the Anatomy of its Rays: You placed a Sheet of white Paper over againſt the Priſm, which Paper received the ſeven primitive Colours, every one in its proper Order. Now expoſe your two Glaſſes to one of the coloured Rays, which you pleaſe, as reflected from the Paper; you ſhall always ſee that coloured Circles will form themſelves between theſe Glaſſes, but that theſe Circles will then be of the Colour of the Rays which are reflected to you from the Paper. Hold up your Glaſſes, for Inſtance, to the Light of the red Rays, and you ſhall have red Circles only between them: But, what is very ſurprizing, between every one of theſe red Circles there will be a Circle quite black. To clear up this Matter, and

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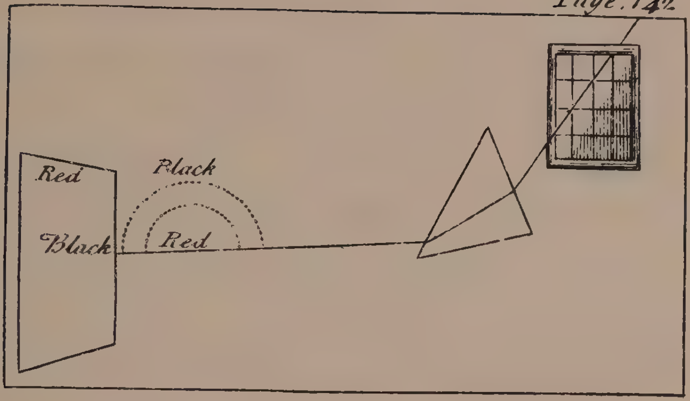

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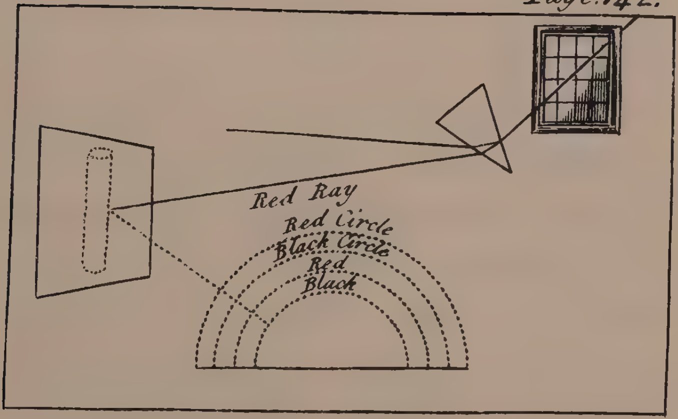

the Singularities that are attached to it, yet more perfectly, take your Glaſſes from the Paper, and preſent them to the Priſm itſelf, in ſuch a manner as that one of the Rays which eſcape from the Priſm, a red one for Example, may fall upon the Glaſſes; ſtill red Circles only will form themſelves between the black ones: then put the Sheet of Paper behind your Glaſſes, and every black Ring will produce a red one on the Paper, and every one that is red when reflected towards you, will produce a black one on the Paper.

It reſults from this Experiment, that the Air or the Water which is between your Glaſſes, reflects the Light in one Place, and in another lets it paſs, or tranſmits it. I confeſs, I cannot here ſufficiently admire that Depth of Penetration, that Sagacity more than Human, with which Sir *Iſaac* has purſued theſe imperceptible Truths; he was ſatisfied of theſe wonderful Propoſitions, even by Meaſure and Calculation.

At the Point of Contact of the two Glaſſes, you ſee no Reflection of any Light: immediately after this Contact, the firſt and thinneſt Body of Water or Air, that touches the black

Point, produces a Reflection: the Water or Air of a ſecond Degree of Denſity, that is, twice as thick as the firſt, reflects nothing: that of the third, which has thrice the Denſity of the firſt, reflects: that of the fourth Degree, like the ſecond, does not reflect: that which has five Times the firſt Thickneſs, tranſmits: that which has ſix, tranſmits nothing. So that the black Circles follow in this Progreſſion, 0, 2, 4, 6, 8, and the coloured and luminous ones in this, 1, 3, 5, 7, 9.

Conſequences of theſe Experiments.

What paſſes in this Experiment, happens in like manner in other Bodies, which all reflect one Part of the Light, and receive another Part of it into their Subſtances. This Property then is fully demonſtrable to the Mind, and even to the Sight, that it is not the ſolid Surface which reflects the Light. For, in ſhort, if ſolid Surfaces did really reflect; 1ſt, The Point of Contact, in the two Glaſſes would have this Quality, and not be obſcure, as we ſee it. 2dly, Every ſolid Part, which gave you only one ſort of Rays, ought alſo to have given you every Species of them. 3dly, The ſolid Parts would not tranſmit the

Light in one Part, and reflect it in another; for being all ſolid, they would all reflect. 4thly, If Light was reflected by ſolid Parts, it would be impoſſible to ſee one's ſelf in a Looking-glaſs, as we have before ſaid; becauſe the Glaſs being rugged and uneven, could not ſend back the Light in a regular manner *. It is indubitable then, that there is a Power acting about Bodies, without touching them, and that this Power acts between theſe Bodies and the Light. In a Word, far from ſtriking on the Bodies themſelves, and rebounding back to us, we have reaſon to believe that the greateſt Part of the Rays of Light which impinge againſt ſolid Parts, remain there, are there loſt, are there extinguiſhed.

This Power, which acts about Surfaces, acts from one Surface to another. It is chiefly from the laſt Surface, on the farther ſide of a tranſparent Body, that the Rays rebound: We have proved this before.

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* And yet it does, becauſe ſmoother than other Surfaces, though many Rays are loſt by ſome Degrees of Ruggedneſs; but if there be no Contact, no matter whether rugged or ſmooth, the Power of reflecting might reſide with the one as well as the other.

The mutual Action of Bodies upon Light.

We muſt admit a Power then, which acts upon the Rays of Light from above one of theſe Surfaces to the other, a Power which tranſmits and reflects the Rays alternately. This Play between Light and Bodies was not merely ſuſpected by Sir *Iſaac Newton*; he has computed many thouſands of theſe alternative Vibrations, theſe tranſmitted and reflected Throws. But, this Action of Bodies upon Light, and of Light upon Bodies, leaves us yet many Uncertainties in the manner of explaining it.

Conjectures of Sir Iſaac Newton.

He who diſcovered this Myſtery, was not able, in the Courſe of his long Life, to make Experiments enough to aſſign the certain Cauſe of theſe Effects. But even tho' by his Diſcoveries he had taught us only new Properties of Matter, would not this alone have been a ſufficient Service rendered to Philoſophy? He conjectured that Light flows from the Sun, and other luminous Bodies, by Starts, by Vibrations; that the firſt of theſe Vibrations operates a Reflection, the ſecond a Tranſmiſſion, and ſo on to Infinity. He had alſo prepared Experiments, which might conduce to ſhew us wherein this Sport of

Nature agrees with the Grand Principle of Attraction: but he had not Time to finiſh his Reſearches. He conjectured moreover, that there is in Nature a very elaſtic and thin Matter, which becomes by ſo much the more thin, as it is farther diſtant from opaque Bodies; that the Starts or Throws of Light excite Vibrations in this elaſtic Matter: And it muſt be confeſſed, that this Hypotheſis accounts for almoſt all the Myſteries concerning Light, and above all for the Attraction and Gravitation of Bodies. But an Hypotheſis, even tho' it gives a Reaſon for almoſt every thing, ought not to be admitted. It is not ſufficient that a Syſtem be poſſible to make it be believed; it ought to be proved. If the Vortices of *Deſcartes* could ſupport themſelves againſt all the Difficulties with which they are embarraſſed, it would nevertheleſs be neceſſary to reject them, becauſe they are merely poſſible: therefore we will not lay any real Streſs upon the Conjectures even of Sir *Iſaac Newton* himſelf.

But we muſt not rely on Conjectures.

If I ſpeak of them, it is rather to publiſh the Hiſtory of his Thoughts, than to draw the leaſt Concluſion from his Ideas, which

I look upon as the Dreams of a great Man. He did not at all build upon them himſelf: He was contented with Facts, without daring to determine any thing concerning their Cauſes. Let us paſs to the other Diſcovery, the Agreement which exiſts between the Rays of Light and the Notes in Muſick.

CHAP. XIV.

Of the Reſemblance between the ſeven Primitive Colours and the ſeven Notes in Muſick.

IT was you know perceived, a very long Time before *Deſcartes*, that a Priſm expoſed to the Sun exhibits the Colours of the Rainbow. Colours had often been ſeen to paint themſelves upon Linnen, or upon white Paper, in an Order which is always the ſame. The Curious ſoon proceeded, from Experiment to Experiment, even to meaſure the Space that is occupied by every one of theſe Colours. At laſt it was found, that theſe Spaces are the ſame with regard to one another, as thoſe of the Lengths of a Cord, that expreſſes the ſeven Notes in Muſick. I had often heard it ſaid, that *Newton* had taken from *Kircher* this Diſcovery of the Analogy between Light and Sound. *Kircher* indeed, in his *Ars Magna Lucis & Umbræ*, and in others of his Works, denominates Sound the Ape of Light. Some Perſons

A very remarkable Thing in Kircher.

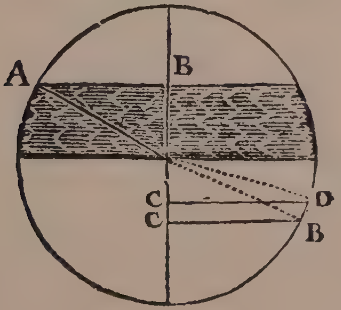
ſons have inferred from hence, that *Kircher* was acquaintted with the Particulars in which they agree: but it is proper, to prevent a Miſtake, to lay before the Reader what he ſays, in his 146th and following Pages. "Thoſe, ſays he, who have a loud and "ſtrong Voice, partake of the Nature of an "Aſs: they are indiſcreet and petulant, as "Aſſes are known to be; and this Voice "holds a reſemblance with the black Co-"lour. Thoſe whoſe Voice is grave at the "firſt, and afterwards ſharp, partake of the "Ox: they are, like that Animal, dull and "cholerick, and their Voice anſwers to a "ſky-blue."

He takes care to ſtrengthen theſe fine Diſcoveries by the Teſtimony of *Ariſtotle*. This is all that Father *Kircher* teaches us, who was otherwiſe one of the greateſt Mathematicians, and moſt Learned Men of his Age; and it was thus, in a manner, that all thoſe who were merely Scholars reaſon'd at that Time. Let us proceed now to the Reaſoning of Sir *Iſaac*.

Manner of knowing the Proportions of the ſeven primitive Colours of Light.

There are, you well know, ſeven principal Rays in every Ray of Light, which have all their Refrangibility: every one of theſe Rays hath its Sine, and every one of theſe Sines its Proportions with the common Sine of Incidence; obſerve what paſſes in theſe ſeven primitive Rays, which part by dividing in the Air.

It is not our Buſineſs here to conſider, that even in the Glaſs all theſe Rays are ſcattered, and that every one of them there hath a different Sine: We muſt regard the Aſſemblage of Rays in the Glaſs as a ſingle Ray, which has only the common Sine A, B. But in emerging from the Glaſs, every one of theſe Rays viſibly ſeparating from the reſt, each hath its different Sine; that of red (the leaſt refrangible Ray) is deſcribed by the Sine C, B; that of violet (the moſt refrangible of all) by the Line C, B, D.

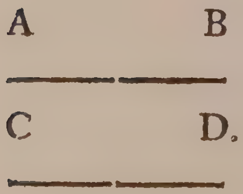


Theſe Proportions being ſettled, let us ſee what is this Agreement, no leſs exact than ſingular, between Colours and Muſick. Let the Sine of Incidence of the white Collection of Rays be to the Sine of Emergence of the red Ray, as this Line A, B, is to the Line B, C.

The Sine given in the Glaſs

The Sine given in the Air

Let the ſame Sine of Incidence A, B, be to the Sine of Refraction of the violet Ray, as the Line A, B, is to the Line C, D.



You perceive that the Point B is the Limit of the leaſt Refrangibility, and D the Limit of

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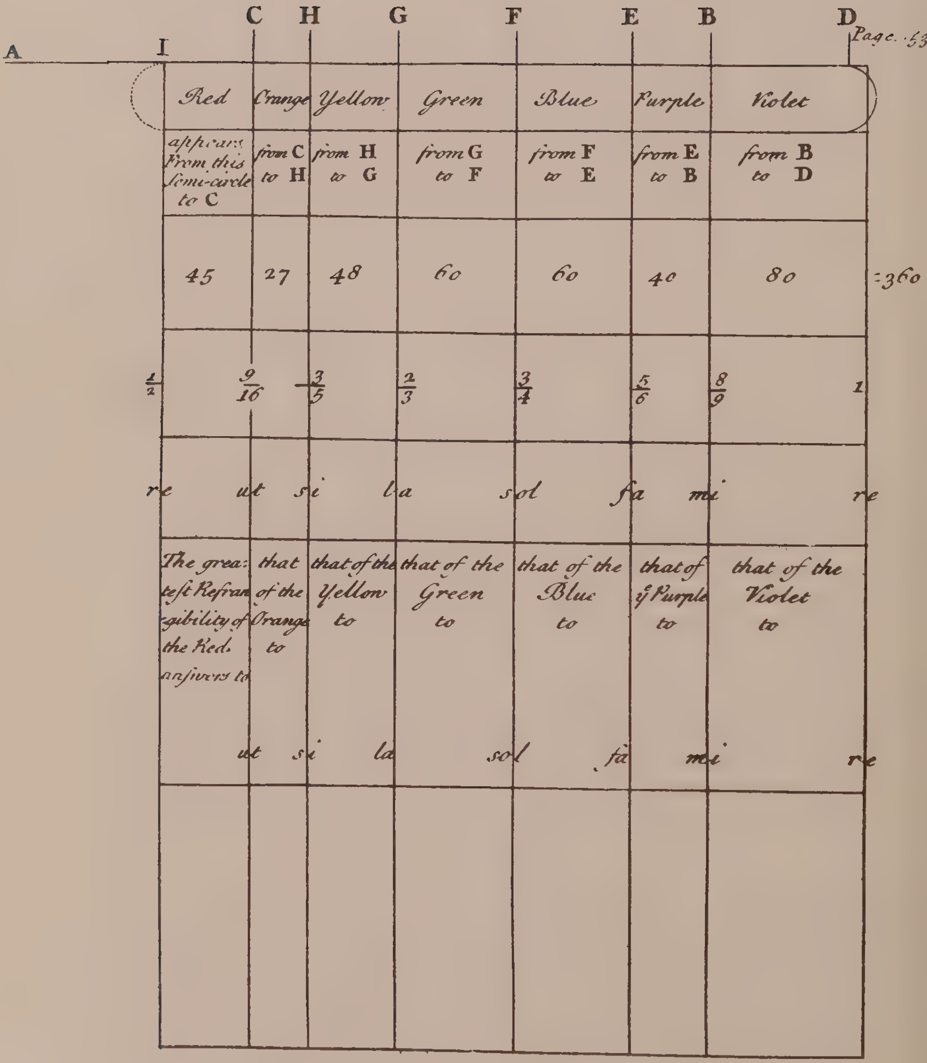
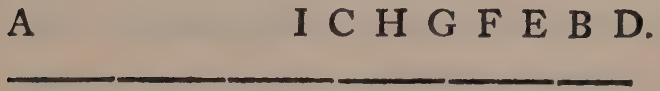


Red	Orange	Yellow	Green	Blue	Purple	Violet
appears from this ſemi-circle to C	from C to H	from H to G	from G to F	from F to E	from E to B	from B to D
45	27	48	60	60	40	80
The greateſt Refrangibility of the Red anſwers to	that of the Orange to	that of the Yellow to	that of the Green to	that of the Blue to	that of ye Purple to	that of the Violet to

of the greateſt: the ſmall Line B, D, contains then all the Degrees of Refrangibility of the ſeven Rays. Double now the Line I, D, in the Scheme anſwering B, D, above, ſo that I, may become the middle, as in this Figure or the Scheme annexed.



Then the Length from A to C makes the red; the Length from A to H, the orange; that from A to G, the yellow; that from A to F, the green; that from A to E, the blue; that from A to B, the purple; that from A to D, the violet. Now the Spaces here given are ſuch, that every Ray may be refracted, a ſmall matter more or leſs, in every one of theſe Spaces, but can never go beyond the Space preſcribed it: the violet Ray will play between B and D, the red Ray between C and I, and ſo of the reſt; the whole in ſuch Proportion, that if you divide the Length from I to D into 360 Parts, every Ray ſhall have to itſelf the Dimenſions that are exhibited in the large Scheme hereunto annexed.

The Analogy between the Notes in Muſick and the ſeven Colours.

Theſe Proportions are preciſely the ſame as thoſe of the Notes in Muſick. The Length of the Cord, which, being ſtretched, ſhall ſound *Re*, is to the Cord which ſhall give the Octave of *Re*, as the Line A, I, which gives the red in I, is to the Line A, D, which gives the violet in D: ſo that the Spaces which mark the Colours, in this Figure, mark alſo the Notes in Muſick.

The greateſt Refrangibility of the violet anſwers to *Re*; the greateſt Refrangibility of the purple, to *Mi*; that of the blue, to *Fa*; that of the green, to *Sol*; that of the yellow, to *La*; that of the orange, to *Si*; that of the red, to *Ut*; and, in a Word, the leaſt Refrangibility of the red agrees with *Re*, which is the higheſt Octave. And one may form a compleat Idea of all theſe Proprieties, by caſting his Eyes on the Table which I have drawn up, and which he will find over againſt the Obſervations in the preceding Page.

There is another Reſemblance between Sounds and Colours, which is, that the moſt diſtant Rays, the violet and the red, ſtrike our Eyes at the ſame Time, and that the moſt diſtant Sounds, the graveſt and the ſharpeſt, come alſo to our Ears with equal Velocity. I do not mean by this, that we ſee and hear Things at the ſame Diſtance in the ſame Time; for Light makes an Impreſſion on us, at leaſt ſix hundred thouſand times ſooner than Sound; but the Senſe is, that blue Rays, for Example, come not from the Sun to our Eyes ſooner than red Rays, in like manner as the Sound of the Note *Si* does not reach our Ears ſooner than that of the Note *Re*.

This Analogy between Light and Sound gives room for a Suſpicion, that all Things in Nature have ſecret Relations, which perhaps may be diſcovered hereafter. It is already certain, that there is an Agreement between *Feeling* and *Sight*, ſince Colours depend upon the Configuration of Parts *. It is even maintained, that there have been Perſons who were born blind, that could by their Feeling diſtinguiſh the Difference between white, black, and ſome other Colours.

An ingenious Philoſopher has attempted to puſh this Relation between Seeing and Hearing farther, perhaps, than it may ſeem permitted for Men to proceed. He has contrived an ocular Harpſicord, which is to exhibit a Succeſſion of harmonic Colours, as our Harpſicords do of Sounds: He has work'd at it with his own Hands, and pretends that in Time he ſhall be able to play Tunes to the Eyes. Doubtleſs we cannot but thank a Man, who takes ſuch Pains to introduce new Sciences, and new Pleaſures among us: There have been Countries, where he would have received a publick Recompence. It is certainly to be wiſhed, that this Invention may not be, like ſo many others, a very ingenious, but unprofitable Effort. This rapid Paſſage of a great many Colours before the Eyes, it is to be feared, will be more likely to aſtoniſh, dazzle, and fatigue the Sight. Our Eyes, perhaps, may have need of Repoſe, in order to enjoy the Agreeableneſs of Colours. It is not enough to propoſe a Pleaſure to us; Nature muſt have made us capable of receiving that Pleaſure. In a Word, it is Experience alone that muſt juſtify this Invention. Mean while, methinks every equitable Judge cannot but praiſe the Efforts of ſuch a Genius, as endeavours to en-

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* Or as before on the Thickneſs of their Surfaces.

Idea of an Ocular Harpſicord.

enlarge the Carrier of Arts, and that of Nature.

We will not extend this Introduction concerning Light any farther; perhaps we have already ſaid too much of it in a Treatiſe of Simple Elements: but the greateſt Part of theſe Truths are new to moſt Readers. Before we go on to the other Part of this Philoſophy, let us remember, that the Theory of Light hath ſomething in common with the Theory of the Univerſe, on which we are now to enter. This Theory is, that there is a kind of Attraction obſerved between Light and Bodies, as well as among all the Orbs of our Univerſe, which we are next to conſider. Theſe Attractions are diſcovered by different Effects; but, in brief, Attraction is always a Tendency of Bodies to one another, without any apparent Impulſion.

All this Theory of Light has Relation to the Theory of the Univerſe.

Among ſo many Properties of Matter, ſuch as thoſe Fits of Tranſmiſſion and Reflection of Light, that Repulſion which Light meets with in the Void, in the Pores of Bodies, and about their Surface; among all theſe Properties, I ſay, we ought chiefly to fix our Attention to that Power by which the Rays are reflected and broken, to that Force by which Bodies act upon Light, and Light upon Bodies, without ever touching each other. *Matter has more Properties than has been imagined.* Theſe Diſcoveries may ſerve, at leaſt, to render us extremely circumſpect in our Deciſions concerning the Nature and Eſſence of Things. Without the Senſe of Feeling, we could have no Idea of the Extenſion of Bodies; without our Eyes, we could not think of ſuch a Thing as Light; if we had never moved ourſelves, we could never have believed the Mobility of Matter *: the ſmall Number of Senſes which God has given us, can diſcover to us but a few of the Properties of Matter. Our Reaſon ſupplies the want of other Senſes, and teaches us that Matter has yet other Attributes, as Attraction and Gravitation. In all Probability it has many more belonging to its Nature, of which Philoſophy, perhaps, may hereafter give ſome Ideas to Mankind.

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* Some think actual Motion might be known, by ſeeing Bodies change their Diſtance from one another when we are at reſt.

CHAP. XV.

*Introductory Ideas concerning Gravity and the Laws of Attraction: That the Opinion of a ſubtil Matter, Vortices, and a Plenitude, ought to be rejected *.*

AN intelligent Reader, who ſhall have conſidered with Attention theſe wonderful Properties of Light, convinced by Experience that they are not produced by any known Impulſe, will doubtleſs be impatient to know more of this new Power which we have ſpoken of under the Name of *Attraction*, and which muſt needs act more ſenſibly upon all other Bodies than upon that of Light. That we may not any more be frighted with Terms, let us examine ſimply the Facts.

Attraction.

I ſhall make uſe indifferently of the Words *Attraction* and *Gravitation*, in ſpeaking of Bodies, whether they ſenſibly tend towards one another, or turn in immenſe Orbs round one common Centre, or fall upon the Surface of the Earth, or unite to compoſe ſolid Bodies, or, laſtly, globify themſelves in Drops to form Liquids. Let us enter upon our Subject.

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* But not that ſubtile Æther which Sir *Iſaac* makes the Cauſe of Attraction, Refraction, Animal Motion, &c. which pervades the Univerſe.

All known Bodies gravitate; and the Notion of ſpecifick Levity has been a long Time counted among the acknowledg'd Errors of *Ariſtotle* and his Followers.

Since the Invention of the famous pneumatic Engine, or Air-Pump, we have been in a much fairer Way to know the Gravity of Bodies; for when they fall in the Air, the Particles of that Element ſenſibly retard the downward Motion of thoſe Bodies which have large Surfaces and little Subſtance; but in that Machine deprived of Air, Bodies being abandon'd to that Force, whatever it be, which precipitates them without Obſtacle, do fall according to their whole Weight.

The pneumatic Engine, invented by *Otto-guerick*, was ſoon after brought to Perfection by Mr. *Boyle*; it was furniſhed with Glaſs Recipients much longer than at firſt, and theſe were entirely deprived of Air. In one of theſe long Recipients, compoſed of four Tubes, the whole together being eight Foot high, were ſuſpended at the Top, by a Spring,

An Experiment which demonſtrates a Vacuum, and the Effects of Gravitation.

Pieces of Gold, Bits of Lead, Scraps of Paper, and Feathers; the Queſtion was, to know what would be the Conſequence, when the Spring was let fly. The philoſophical Gentlemen foreſaw, that the whole would come to the Bottom at the ſame Time: But much the greateſt Number were confident, that the moſt ſolid Bodies would fall with far greater Velocity than the Reſt. The Multitude, which is almoſt always in the wrong, was aſtoniſh'd at the Event; for in every Experiment that was made, the Gold, the Lead, the Paper, and the Feathers, deſcended equally ſwift, and came to the Bottom of the Recipient in one and the ſame Inſtant,

Thoſe who ſtill held for the *Plenitude* of *Deſcartes*, and for the pretended Effects of the ſubtile Matter, could not give any good Reaſon for this Fact; for Facts were the Rocks on which they ſplit. If there was an abſolute Plenitude, tho' we allowed there might notwithſtanding be ſuch a Thing as Motion, (which is abſolutely impoſſible) at leaſt this pretended ſubtile Matter muſt exactly fill all the Recipient; it muſt be there in as great Quantity as Water, or Mercury, that might have been put there; it muſt reſiſt the Pieces of Paper, according to their Surfaces, and let the Gold and the Lead deſcend much ſooner: But this Deſcent is performed in the ſame Inſtant; therefore there is nothing in the Recipient that reſiſts; therefore the pretended ſubtile Matter cannot produce any ſenſible Effect in this Recipient; therefore there is ſome other Power which cauſes Gravity.

It would be in vain to ſay, that there may poſſibly remain a ſubtile Matter in the Recipient, becauſe it is penetrated by the Light: There is a great deal of Difference in the two Caſes. The Light, which is in this Glaſs Veſſel, does not fill, at the moſt, the hundred thouſandth Part of it; but according to the *Carteſians*, we are to imagine that their ſubtile Matter fills it much more compleatly than if I ſuppoſed it full of Gold; for there is a great deal of Vacuum in Gold, but they admit none in ſubtile Matter.

Bodies gravitate in proportion to the Quantity of their Matter.

Now by this Experiment, the Piece of Gold, which weighs an hundred thouſand Times as much as the Paper, deſcends with the ſame Velocity as the Paper; therefore the Power, which makes it deſcend, acts an hundred thouſand Times more forcibly upon the Gold, than upon the Paper; in like manner as a hundred Times more Strength is requiſite in my Arm to move an hundred Pounds, than to move one Pound. That Power then, which is the Cauſe of Gravitation, acts in direct Proportion to the Quantity of Matter in Bodies. In Effect, it acts ſo according to the Quantity of Matter in Bodies, and not according to their Surfaces, that a Pound of Gold reduced into Duſt, will weigh preciſely as much as the ſame Quantity beat out into Leaves. The Figure of Bodies makes no Alteration in their Gravity; the Power of Gravitation then operates upon the internal Nature of Bodies, and not in proportion to their Superficies.

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* Yea, the Needle in it would turn to its Point..

† Sure there is Light at each Part where a Mite is viſible.

Whence the Power of Gravitation proceeds.

This Power does not reſide in the pretended ſubtile Matter, of which we ſhall ſpeak in the next Chapter: That Matter muſt be a Fluid; and every Fluid acts upon Solids in proportion to their Superficies. Thus the Veſſel preſenting a ſmaller Surface at her Prow, cuts through the Sea which would reſiſt her

Sides. Now if the Superficies of a Body be the Square of its Diameter, the Solidity of this Body is the Cube of the ſame Diameter: But the ſame Power cannot act at one Time in proportion to the Cube and the Square; therefore the Gravity of Bodies is not the Effect of this Fluid. Beſides, it is impoſſible that this pretended ſubtile Matter ſhould, on the one Side, have ſo much Force as to precipitate a Body from the Height of 54000 Feet in a Minute (for ſuch is the Deſcent of Bodies) and that, on the other, it ſhould be ſo weak, as not to hinder the lighteſt Wooden Pendulum to proceed from Vibration to Vibration in the pneumatic Engine, which is ſuppoſed to be compleatly filled with this imaginary Matter.

I ſhall make no Scruple then to affirm, that if any Impulſe ſhould ever be diſcovered, which is truly the Cauſe of the Tendency of Bodies towards a Center, the Cauſe, in a Word, of Gravitation and Attraction, that Impulſe will be altogether of a different Nature from any Thing we are acquainted with *.

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* Every Body muſt tend to the Center of the Earth, if there be a Vacuum or little Reſiſtance there.

There is one primary Truth then, that was pointed out elſewhere, and has been proved in this Chapter, that there is a Power, which occaſions all Bodies to gravitate, in exact Proportion to the Quantity of their Matter.

Why one Body weighs more than another.

If it be actually enquired, why one Body is more ponderous than another, the ſingle and only Reaſon of it will eaſily be found: It will be concluded, that this Body muſt have more Solidity, more Matter under the ſame Extent: Thus Gold is heavier than Wood, becauſe there is in Gold much more Matter, and much leſs Vacuity, than in Wood.

The Syſtem of Deſcartes *cannot account for it.*

Deſcartes and his Followers maintain, that one Body is heavier than another without containing more Matter. Not content with this Idea, they ſupport it by another altogether as falſe: They admit a grand Vortex, Tourbillon or Whirlpool, of ſubtile Matter, encompaſſing our Globe; and it is this grand Vortex, ſay they, that in its Circulation drives all Bodies towards the Center of the Earth, and impreſſes on them that Quality which we call Gravity.

It is true, they have not given any Proof of this Aſſertion*. There is not the leaſt Experiment, not the leaſt Analogy in Things of which we have any Knowledge, whereon to eſtabliſh even a ſlight Preſumption in favour of this Whirlpool of ſubtile Matter; ſo that for this very Reaſon alone, that this Syſtem is a mere Hypotheſis, it ought to be rejected: Nevertheleſs, it was on no other Account that it obtained Credit. This Vortex was conceived without Difficulty; an indefinite Explanation of Things was given, by pronouncing the Words *ſubtile Matter*; and when the Philoſophers were ſenſible of the Contradictions and Abſurdities that cleav'd to this philoſophical Romance, they dream'd rather of correcting than abandoning it.

Huygens and many others have made in it a thouſand Corrections, of which they themſelves confeſs the Inſufficiency: But what ſhall we put in the Place of theſe Tourbillons, and this ſubtile Matter? It was this too common Way of Reaſoning, more than any Thing, that confirm'd Men in the Error they had embraced. But we ought to abandon what is manifeſtly falſe and inſupportable, as well when we have nothing to ſubſtitute in its Room, as when we have the Demonſtrations of *Euclid* to put in its Place. An Error is neither more nor leſs an Error, whether the Loſs of it be or, be not, ſupplied by Verities. Ought I to admit the horrid Notion of a Vacuum in a Pump, becauſe I am not yet able to judge, by what Mechaniſm the Water riſes in that Pump*?

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* This is a great Condeſcention.

Before we proceed any farther then, let us take upon us to prove that the Vortices of ſubtile Matter have no Exiſtence; that the Idea of Plenitude is not leſs chimerical; that therefore the whole Syſtem, founded on theſe Imaginations, is no more than an ingenious Romance, without the Appearance of Truth. We will enquire firſt, what is meant by theſe Vortices; and afterwards examine, whether or no a Plenitude be poſſible.

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* *Deſcartes* does not require us to believe a Vacuum in a Pump, he explains it by a Plenum; for the Sucker being drawn upwards, preſſes the Matter above it, which Preſſure is continued to the Surface of the Water at the Bottom of the Pump, which preſſes the Water up the ſame Inſtant, all being full.

CHAP. XVI.

That the Vortices and Plenitude of Deſcartes *are impoſſible, and conſequently that there is ſome other Cauſe of Gravity.*

DESCARTES ſuppoſes an immenſe Heap of imperceptible Particles, which carries the Earth round, with a rapid Motion from Weſt to Eaſt, and which from Pole to Pole moves parallel with the Equator. This Vortex of Matter, which extends beyond the Moon, and drags her alſo along with it in its Courſe, is encloſed in another Vortex yet much more extenſive, which touches another yet larger, without being confounded with it; and ſo on.

Proof of the impoſſibility of the Vortices.

If this were ſo, 1ſt, the Vortex which is ſuppoſed to move round the Earth from Weſt to Eaſt, would drive the Bodies that are upon the Earth from Weſt to Eaſt alſo*: Now all Bodies, in falling, deſcribe a Line, which, being prolonged, would paſs very near thro' the Centre of the Earth: therefore this Vortex has no Exiſtence. 2

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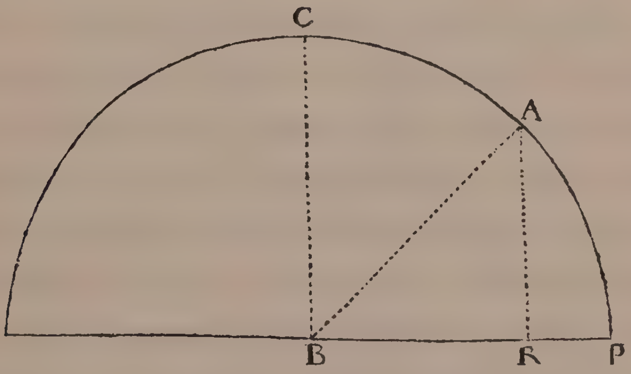
* Not if the Earth move along with it as it does with our Atmoſphere which moves but very little faſter.

2dly, If the Circles of this pretended Vortex moved and acted parallel to the Equator, all Bodies muſt fall perpendicularly, every one under that Circle of the ſubtle Matter to which it anſwers: a Body in A, near the Pole P, muſt, according to *Deſcartes*, fall in R *.



Whereas it falls, within a Trifle, according to the Line A, B, which makes a Difference of about 1400 French Leagues; for we may compute near that Number from the Point R, to the Equator of the Earth B; therefore this Vortex hath no Exiſtence.

3dly, If this Vortex of Matter around the Earth, and thoſe other pretended Vortices around Jupiter, Saturn, *&c.* exiſted; all theſe immenſe Vortices of ſubtile Matter, rowling ſo rapidly in different Directions, could never ſuffer any one Ray of Light, darted from a Star, to come to us in a right Line. Now it has been proved that theſe Rays arrive in a very ſhort Time, conſidering the immenſe Way they come: Therefore there are no Vortices.

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* This is an Argument of ſome Weight, except we ſuppoſe that Bodies tend to the Center, where there is leſs Reſiſtance, as the Winds do.

4thly, If theſe Vortices carried round the Planets from Weſt to Eaſt, the Comets, which traverſe theſe Spaces, in all Directions, from Eaſt to Weſt, and from North to South, could not traverſe them at all. And tho' it ſhould be ſuppoſed, that the Comets have never actually paſs'd from North to South, and from Eaſt to Weſt, yet nothing would be gain'd by this Evaſion; for it is known, that when a Comet is ſeen in the Region of Mars, of Jupiter, of Saturn, it moves incomparably ſwifter than Mars, than Jupiter, or than Saturn; therefore it cannot be carried round by the ſame Bed of fluid Matter which is ſuppoſed to carry round thoſe Planets *; and therefore no Vortices.

5thly, Theſe Vortices muſt be either equally denſe, equally compact with the Pla-

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* Except there be a ſuſpended Force.

nets, or they muſt be more denſe, or, finally, they muſt be leſs denſe. In the firſt Caſe, the pretended Matter, which encompaſſes the Moon and the Earth, being ſuppoſed equally denſe with the ſame Bulk of Earth, we ſhould experience the ſame Reſiſtance, in lifting, for Inſtance, a Cubic Foot of Marble, as we ſhould in lifting a Column of Marble as high as from the Earth to the Moon, whoſe Baſis was only a Foot ſquare. In the ſecond Caſe, the fluid Matter being heavier than the Earth, our Globe would ſwim upon this Fluid, as a Veſſel ſwims upon the Water, and could not be plunged, as is pretended, into the ſubtile Matter. In the third Caſe, the Fluid being leſs denſe, leſs weighty than the Earth, this Fluid could never ſuſtain it, for the ſame reaſon as Water cannot ſuſtain Iron, nor any thing that weighs more than itſelf *: Therefore no Vortices.

6thly, If theſe imaginary Fluids had any Exiſtence, all the Order of rhe Celeſtial Orbs would be inverted: The Sun, which turns upon its own Axis, would ſoon loſe its Motion

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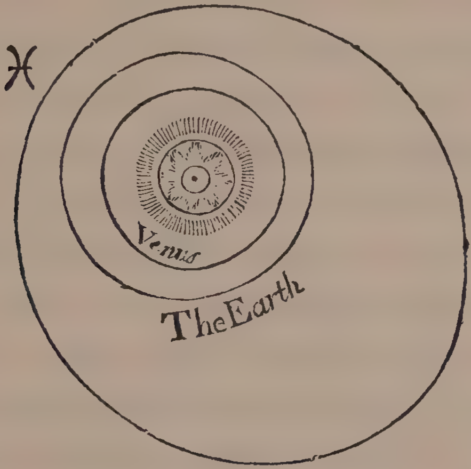
* If there be a Plenum no Body is more denſe than another, only it contains more of Homogeneous Matter.

tion from the Obſtruction of this Fluid; and not one of the Planets would keep the Courſe it now holds, would have the Motion it now has, or would long have any Motion at all.

7thly, The Planets carried round in theſe Vortices could move circularly only, becauſe the Vortices, at equal Diſtances from the Center, muſt be equally denſe; but the Planets move in Eclipſes, and there cannot be carried round in any ſuch Vortices; therefore no ſuch Vortices exiſt.

8thly, The Earth has her Orbit, which ſhe paſſes thro', beween the Orbit of Venus and that of Mars: All theſe Orbits are elliptical, and have the Sun for their Center: Now when Mars, Venus, and the Earth, are neareſt one to another, the Matter of this pretended Torrent, which carries round the Earth, muſt be much more compreſſed than at other Times: This ſubtile Matter ſhould then precipitate its Courſe, as a River that is ſtraitened in its Banks, or flows under the Arches of a Bridge; and, conſequently, ſhould then force the Earth on with much greater Rapidity, than when it is in any other Poſition: But, on the contrary, it is juſt then that the Motion of the Earth is more retarded than at other Times *.



When Mars appears in the Sign Piſces, that Planet, the Earth, and Venus, are nearly in the Proximity here repreſented; and then the Sun ſeems to be retarded for ſome Minutes, that is, the Earth is retarded: It is demonſtrably impoſſible then, that there ſhould be Torrents of Matter which carry round the Planets: Therefore the Vortices have no Exiſtence.

9thly, Among the more abſtracted Demonſtrations, which deſtroy the Being of theſe Vortices, we will chuſe the following.

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* This would hold good if the Planets were fixed as the Pillars of a Bridge.

By one of *Kepler*'s Fundamental Laws*, every Planet deſcribes equal Areas in equal Times: By another Law not leſs certain, every Planet makes its Revolution round the Sun in ſuch a Manner, that if, for Example, its middle Diſtance from the Sun was 10, by taking the Cube of that Number, which makes 1000, the Time of the Revolution of that Planet round the Sun, will be found proportionable to the Square Root of the Number 1000. Now if there were Torrents of Matter which carried round the Planets, theſe Torrents could not follow theſe Laws; for the Swiftneſſes of the Torrents muſt be proportional to their Diſtance from the Sun, and, at the ſame Time, to the Square Roots of thoſe Diſtances; which is incompatible.

To ſum up the whole; every one ſees what muſt happen to two Fluids, circulating in oppoſition the one to the other: They would neceſſarily be confounded together, and form a Chaos, inſtead of maintaining an Order in Nature. This alone, would at once have expoſed the Carteſian Syſtem to the utmoſt

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* The Period of each Part of the Vortex is as the Cube of its Diſtance.

Ridicule, if the Love of Novelty, and an habitual Diſuſe of free and impartial Examinations, had not prevailed.

Proof againſt a Plenitude.

We are now to prove that the Plenitude, in which theſe Vortices are ſuppoſed to move, is as impoſſible as the Vortices themſelves.

1ſt, A ſingle Ray of Light, which does not weigh any thing near the hundred thouſandth Part of a Grain *, muſt diſcompoſe the Order of the whole Univerſe, if it was to open its way to us thro' an immenſe Space, every part of which would not only reſiſt of itſelf, but the whole Line of Matter which preſſes on it.

2dly, Two hard Bodies, A and B, (we have already proved that there muſt be hard Bodies,) touch one another at one Surface, and are ſuppoſed to be encompaſſed with a Fluid, which preſſes them on all ſides: Now, when they are ſeparated, † it is clear that the pretended ſubtile Matter muſt arrive ſooner at the Point A, where they divide, than at the Point B.

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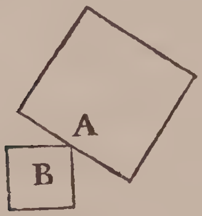
* If his Atoms have any Weight, a Line of them to the Stars, or a Ray, will have conſiderable Weight.

† Two poliſhed Surfaces will not part, by which he proves a Plenum.



There is a Moment then, wherein there muſt be a Void at B; therefore even in the Syſtem of the ſubtile Matter there is a Void.

3dly, If there was no ſuch Thing as Vacuity and Space, there could be no Motion, even in the Syſtem of *Deſcartes* himſelf. He ſuppoſes that God created the Univerſe full, conſiſting of ſmall Cubes *: Let there then be a given Number of Cubes, repreſenting the Univerſe, without their having the leaſt Interval between them: It is evident, that one of them muſt move out of the Place it occupies; for if every one continues in its Place, there can be no Motion, becauſe Motion conſiſts in changing of Place, in moving from one Point of Space to another. Now who does not perceive, that one of theſe Cubes cannot quit its Place, without leaving a Vacuum at the Inſtant it goes out of it;

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* See rather *Deſcartes* himſelf.

ſince it is clear that this Cube, in turning itſelf round, muſt preſent its Angle to the Cube it touches, before that Angle can be beat in Pieces? At that Time then there is Space between theſe two Cubes; therefore, even in the Syſtem of *Deſcartes* himſelf, theſe cannot be Motion without a Vacuum.

4thly, If all was full, as *Deſcartes* would have it, we ourſelves ſhould feel an infinite Reſiſtance in walking, whereas we perceive no other than that of the Fluids in which we are: That of Water, for Example, reſiſts 860 Times, and that of Mercury 14,000 Times, more than that of Air. Now the Reſiſtances of Fluids are in proportion to the Squares of Velocities: Thus if a Man, in a Third of Time, makes his way thro' a Foot of Mercury, which reſiſts him 14,000 Times more than Air; if this Man, in the next Third, move twice as far, the Mercury in this Third, will reſiſt in proportion to the Square of 2 multiplied by 14,000; a Reſiſtance 56,000 Times more powerful than that of Air: If all were full, it would be abſolutely impoſſible to walk a ſtep, to breathe, *&c.* *

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* Reſiſtance is not according to the Quantity of Matter, but to the yielding of the Particles, or parting more or leſs eaſily.

5thly, The *Carteſians* have endeavour'd to elude the Force of this Demonſtration, but they had no other way of doing it, than by advancing a manifeſt Error. They pretend, that this infinite Torrent of ſubtile Matter penetrating all the Pores of Bodies, cannot hinder their Motion. They did not reflect, that every Body, which moves in a Fluid, feels a Reſiſtance in proportion to the Extent of Surface it oppoſes to this Fluid: Now the more Pores there are in a Body, the larger is its Surface: So that the pretended ſubtile Matter, by clogging up all the Inſide of a Body, muſt oppoſe the Motion of that Body much more forcibly, than by touching only its outward Superficies. This is capable of the moſt undeniable Demonſtration.

6thly, All Bodies in a Plenitude would be equally weighty: It is impoſſible to conceive that a Body bears upon me, and preſſes me, but by its Quantity of Matter; a Pound of Gold Duſt weighs as much on my Hand, as a Lump of Gold of a Pound. In vain the *Carteſians* anſwer, that the ſubtile Matter penetrating the *Interſtitia* of Bodies, has no Weight, and that we ought to eſteem nothing

thing weighty but what is not ſubtile Matter. This Opinion, in *Deſcartes*, is no leſs than a direct Contradiction; for, according to him, itis the pretended ſubtile Matter alone that cauſes the Gravity of Bodies, by forcing them towards the Earth*: This ſubtile Matter itſelf then gravitates upon theſe Bodies; and if it doth ſo, there can be no Reaſon why one Body ſhould be more weighty than another, ſince all being equally full, all muſt be equally in Quantity of Matter, whether Solids or Fluids: A Plenitude then, is a Chimæra; there is a Vacuum therefore, and nothing can be done in Nature without a Vacuum; therefore Gravity is not the Effect of a pretended Vortex, in an imaginary Plenitude.

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* But it does not thence follow, that that ſubtile Matter gravitates; for tho' Matter deſcending in one Tube forces it up in another, it does not therefore go up tſelf.

CHAP. XVII.

What is meant by Vacuity *and* Space, *without which there could be neither Gravity nor Motion.*

Objections againſt a Void.

THOSE who cannot conceive a *Void*, object, that this Void muſt be nothing, that nothing cannot have Properties, and therefore, that there can be no Operation in the Void.

Anſwer.

We anſwer, It is not true that a Vacuum is nothing; it is the Place of Bodies; it is Space; it hath Properties; it is extended in Length, Breadth, and Depth; it is penetrable, inſeparable, *&c.* I cannot, indeed, form in my Head an Image of extended Space, as I can of extended Body; but I can demonſtrate to myſelf that this Space exiſts. I cannot repreſent to myſelf, in Geometry, an Infinity of Circles paſſing between a Circle and a Tangent; but I can nevertheleſs demonſtrate to myſelf that the Thing is true in Geometry, which is ſufficient to my Purpoſe. I cannot conceive what it is within me that thinks, yet I am convinced that ſomething thinks within me. In like manner I demonſtrate to myſelf the Impoſſibility of a Plenitude, and the Neceſſity of a Void, without having any Image of a Void: For I can have no Image but of that which is corporeal, and Space is not corporeal. It is one thing to repreſent an Idea to one's ſelf, another thing to conceive a Truth: I have a full Conception of Space; and the *Epicurean* Philoſophers, who were wrong in every thing elſe, conceived it very well.

There was no other Way to anſwer this Argument, than by ſaying that Matter is infinite. This is what many antient Philoſophers have affirmed, and what *Deſcartes* after them has revived.

Matter is not infinite.

But on what Foundation do they imagine that Matter is infinite? Only on another Suppoſition, which they are pleaſed to make. They ſay, Extenſion and Matter are the ſame Thing: We cannot conceive any Limits to Extenſion; therefore we muſt admit that Matter is infinite.

This proves how eaſily Men bewilder themſelves, when they reaſon only on Suppoſitions.

It is falſe that Extenſion and Matter are the ſame Thing: All Matter is extended; but all Extenſion is not Matter. *Deſcartes*, by advancing that there could be no Extenſion but of Matter, advanced a very unphiloſophical Notion; for we know nothing at all of what Matter is; we know only ſome few of its Properties; and no Man can deny, but Millions of other extended Subſtances may exiſt, different from that which we call Matter: Now where muſt theſe Subſtances have their Being, if not in Space?

Beſides this Error, *Deſcartes* contradicts himſelf again; for he admits a God. Now where is this God? He is not in a mathematical Point; he is immenſe: What is his Immenſity, is it not immenſe Space?

With regard to the pretended Infinity of Matter, that Idea hath as little Foundation as the Vortices. We have ſeen the abſolute Neceſſity of a Void in the Order of Things, and that therefore Matter, as it fills not all Space, is not infinite. But what are we to underſtand by an infinite Matter? For the Term *Indefinite*, uſed by *Deſcartes*, either muſt be explained by this, or it ſignifies nothing at

Diſcuſſion of this Truth.

at all. Do they mean, that Matter is eſſentially infinite in its own Nature? If ſo, then Matter is God. Do they mean, that God has created it infinite? Whence do they know that? Do they mean, that Extenſion and Matter are the ſame Thing? The Falſity of that Argument has been ſufficiently proved.

The Exiſtence of infinite Matter, is, at the Bottom, a Contradiction in Terms. But, it will be ſaid, you admit an Immenſity, and Infinity of Space; why do you not admit the ſame concerning Matter? Here lies the Difference: Space exiſts of Neceſſity, becauſe God neceſſarily exiſts; it is immenſe; it is, like Duration, a Mode, an infinite Attribute of a neceſſary, infinite Being. But Matter is nothing of all this: It does not neceſſarily exiſt; and if ſuch a Subſtance were infinite, it would be either an eſſential Attribute of God, or God himſelf: But it is neither the one nor the other; therefore cannot be infinite.

A ſingular Remark.

I ſhall conclude this Chapter with a Remark, which to me ſeems worthy of the utmoſt Attention. *Deſcartes* admitted a God, the Creator and Cauſe of all Things, but he denied the Poſſibility of a Void: *Epicurus* denied that there was a God, the Creator and Cauſe of all, but admitted a Void. Now it was *Deſcartes* who, according to his Principles, ought to have denied a divine Creator, and it was *Epicurus* who ſhould have admitted him. We will prove it evidently.

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* If Space be an Attribute it muſt be in a Subject; not in God, for he is in Space, *Page* 182. *Line* 12.

For if a Void was impoſſible*, if Matter was infinite, if Extenſion and Matter were the ſame Thing, it would follow that Matter muſt be neceſſary: Now if Matter was neceſſary, it muſt exiſt of itſelf by an abſolute Neceſſity, inherent in its primitive Nature, antecedent to all Things: Matter would then be God; therefore he, who maintains the Impoſſibility of a Void*, ought not, if he reaſons conſequentially, to admit any other God than Matter.

On the contrary, if there be a Void, then Matter is not a neceſſary ſelf-exiſtent Being, conſequently, it was created; conſequently, there is a God. It was the Part of *Epicurus* therefore to believe a God, and of *Deſcartes* to deny one *. Wherefore then, on the contrary, is *Deſcartes* continually ſpeaking of a God, the Creator and Preſerver of all Things, and why does *Epicurus* reject ſuch a Being? for this very Reaſon, that Men, in their Sentiments, as in their Conduct, ſeldom follow their own Principles; that their Syſtems, as well as their Lives, are Contradictions.

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* This is not for Void being in the Pores of Bodies.

Concluſion

We learn from all that has been ſaid, that Matter is finite, that there is a Void, that is to ſay, *Space* †, and even incomparably more Space than Matter in our World; for the Quantity of Pores is much more than that of Solids. We conclude that a Plenitude is impoſſible; that the Vortices of ſubtile Matter are equally ſo; that *Deſcartes*'s Cauſe of Gravity and Motion is a Chimera.

We have been taught, by the Experiment in the pneumatic Machine, that there muſt be a Power which occaſions the Deſcent of Bodies towards the Centre of the Earth, that is, which gives them their Gravity; and that this Power muſt act in proportion to the Quantity of Matter of which Bodies conſiſt:

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* He thought it no Reaſon to disbelieve a God, becauſe he could not comprehend his Works.

† Where Matter is there is Space, tho' occupied.

We are now to enquire, what are the Effects of this Power; for if we can make any Diſcovery of its Effects, the Exiſtence of it will be evident. Let us not begin with aſſigning Cauſes, and forming to ourſelves Hypotheſes; that is the ſure Way to wander from the Mark: Let us purſue, Step by Step, that which really paſſes in the Syſtem of Nature*. We are Voyagers, arrived at the Mouth of a River, and muſt labour up the Stream, before we gueſs at the Situation of the Source.

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* The Experiment ſeen muſt not be explained by your Principle, becauſe I can give no other.

CHAP. XVIII.

Gravitation demonſtrated from the Diſcoveries of Galileo *and* Newton: *That the Moon revolves in her Orbit by the Force of this Gravitation.*

Laws of the Gravitation of Bodies found by Galileo.

GALILEO, the Reſtorer of Reaſon in *Italy*, diſcovered this important Propoſition, That heavy Bodies, which deſcend to the Earth (allowing for the ſmall Reſiſtance of the Air) have a Motion accelerated in a certain Proportion, of which I ſhall now endeavour to give a conciſe and clear Idea.

A Body abandoned to itſelf from the Top of the Tower, deſcends, in the firſt ſecond, a Space which is found equal to 15 *Paris* Feet, according to the Diſcovery of *Huygens*, the great Mathematician. It was thought before *Galileo*, that this Body in two ſeconds, would have paſſed thro' only twice the ſame Space, and that thus it would fall 150 Feet in ten ſeconds, and nine hundred Feet in a Minute. This was the general Opinion, and a very probable Opinion it was to a Perſon who did not examine things cloſely. Nevertheleſs, it is certain that in a Minute this Body would fall 54,000 Feet, and 216,000 Feet in two Minutes.

Let us ſee how this Progreſs, which at firſt aſtoniſhes the Imagination, is performed neceſſarily, and with Simplicity. A Body is precipitated with its own proper Weight: That Power, whatever it be, which animates it to deſcend fifteen Feet in the firſt ſecond, acts equally at every Inſtant; for nothing having changed it, it muſt of neceſſity continue the ſame: Thus at the next ſecond, the Body will have the Force which it has acquired in every Inſtant of the firſt, and the Force which it experiences every current Inſtant. Now by the Force which animated it in the firſt ſecond, it deſcended 15 Feet; it hath ſtill that Force then, when it deſcends the next ſecond. It hath beſide that the Force of 15 other Feet, which it acquired by deſcending this firſt ſecond, and that makes 30. It muſt ſtill have alſo in the ſecond ſecond (nothing being changed) the Power of falling 15 Feet which makes 45. By the ſame Reaſon, this

Body will deſcend 75 Feet at the third ſecond; and ſo proportionately in the reſt.

Hence it follows, 1ſt, That in equal Times infinitely ſmall, a moving Body acquires Degrees of Velocity infinitely ſmall, which accelerate its Motion towards the Center of the Earth, provided it meets no Reſiſtance.

2dly, That the Degrees of Velocity which it acquires, are in proportion to the Degrees of Time it employs in deſcending.

3dly, That the Spaces it paſſes through, are as the Squares of theſe Times, or of theſe Degrees of Velocity.

4thly, That the Progreſſion of Spaces paſſed through by this moving Body, are as the unequal Numbers 1, 3, 5, 7. This neceſſary Knowledge of a Phenomenon, that happens on every Side of us every Moment, ſhall be render'd ſenſible, even to thoſe who may at firſt be a little embarraſs'd with all theſe Proportions: They need only caſt their Eyes, with a little Attention, on the Table annex'd, which every Reader may enlarge at his Pleaſure.

Times in which the Body falls.	Spaces which it paſſes through in every Time.	Spaces paſſed over, which are as the Spaces of the Times.	Unequal Numbers, which mark the Progreſſion of Motion, and the Spaces paſſed over.
1ſt Second, one Velocity.	The Body deſcends 15 Feet.	The Square of 1 is 1. The Body falls 15 Feet.	Once fifteen.
2d Second, two Velocities.	The Body deſcends 45 Feet.	The Squares of two Seconds or two Velocities, is four. Four times fifteen are 60. The Body then has deſcended 60 Feet, that is 15 in the firſt ſecond, and 45 in the ſecond.	Three Times fifteen. Thus the Progreſſion is from one to three in this ſecond.
3d Second, three Velocities.	The Body deſcends 75 Feet.	The Square of 3 ſeconds is 9: Nine Times 15 makes 135. The Body then has deſcended 135 Feet in 3 Seconds.	Five Times fifteen. Thus the Progreſſion is viſible according to the unequal Numbers 1, 3, 5, &c.

It is manifeſt at firſt Thought, that in every Inſtant infinitely ſmall, the movable Body receives an accelerated Motion; ſince it appears, both by the Propoſition and the Experiment, that this Motion augments continually. A ſlight Inſpection of this little Table will demonſtrate, that at the End of a Minute the Body will have deſcended 54,000 Feet, for 54,0000 make the Square of 60 Seconds, multiplied by 15. Now 15 multiplied by the Square of 60, which is 3,600, the Product is 54,000.

Theſe Experiments gave Birth to a new Conjecture, in reality well founded, but which nevertheleſs required a particular Demonſtration. For, obſerving that a Body, of a Weight almoſt equal, deſcended 60 Times as faſt at the End of 60 Minutes as it did during the firſt Minute, it was preſumed that the Weight itſelf muſt vary, in ſome certain Proportion to its Diſtance from the Center of the Earth. Several great Men, who ſought a new Road to the Knowledge of Nature, and among others the famous Lord *Bacon*, Chancellor of *England*, began alſo to ſuſpect that there was a Gravitation, an Attraction of Bodies to the Center of the Earth, and of the Earth to Bodies. He propoſed, in his excellent Book, *Novum Scientiarum Organum*, the making of Experiments with Pendulums upon the Tops of the higheſt Towers, and at the Bottom of the deepeſt Wells: For, ſaid he, if the ſame Pendulums vibrate more rapidly at the Bottom of a Well than on the Top of a Tower, we muſt conclude that Gravity, which is the Principle of theſe Vibrations, will be much more powerful at the Centre of the Earth, to which the Well is neareſt. He attempted alſo to make Experiments of the Deſcent of Bodies from different Elevations, and to obſerve if they deſcended leſs than fifteen Feet the firſt ſecond : But there never appeared any Variation in theſe Experiments, the Elevations and Profundities where they made them being of too little Conſequence.

In this Uncertainty they continued, and the Idea of a Power acting from the Center of the Earth remained a random Conjecture.

Deſcartes was acquainted with theſe Particulars, and even ſpeaks of them in treating of Gravity : But Experiments, which alone could clear up this grand Queſtion, were ſtill wanting. The Syſtem of the Vortices hurried away this vaſt and ſublime Genius: It was his Pleaſure, in creating his Univerſe, to give the Direction of every thing to his ſubtile Matter, which he made the Diſpenſer of all Motion and all Gravity. By little and little *Europe* adopted his Syſtem, for want of a better.

Experiment made by ſome Academicians, which conduced to this Diſcovery.

At laſt in 1672, Mr. *Richer*, in a Voyage to *Cayenna*, near the Line, undertaken by Order of *Lewis* XIV. under the Protection of *Colbert*, the Father of all the Arts; *Richer*, I ſay, among many Obſervations, found that the Pendulum of his Clock no longer made its Vibrations ſo frequently as in the Latitude of *Paris*, and that it was abſolutely neceſſary to ſhorten it by a Line, that is, eleventh Part of our Inch, and about a Quarter more *.

Natural Philoſophy and Geometry were not then, by far, ſo much cultivated as at preſent. Who could have believed, that from this Remark, ſo trifling in Appearance, that from the Difference of the eleventh of our

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* A Foot in Meaſure at *Paris* being more than an *Engliſh* Foot, ſo is their Digit or 12th Part of it more than our Inch, in proportion as 144 to 135.

Inch, or thereabouts, could have ſprung the greateſt of phyſical Truths? It was found, at firſt, that Gravity muſt needs be leſs under the Equator, than in the Latitude of *France* *, ſince Gravity alone occaſions the Vibration of a Pendulum †.

The Earth higher in Proportion at the Equator than at the Poles.

In Conſequence of this it was diſcovered, that, whereas the Gravity of Bodies is by ſo much the leſs powerful, as theſe Bodies are farther removed from the Center of the Earth, the Region of the Equator muſt abſolutely be much more elevated than that of *France*; and ſo muſt be farther removed from the Center; and therefore, that the Earth could not be a Sphere. Many Philoſophers, on occaſion of theſe Diſcoveries, did what Men uſually do, in Points concerning which it is requiſite to change their Opinion; they oppoſed the new-diſcovered Truth. Many Doctors of the Church, even till the fifteenth Century, had believ'd the Earth to be flat, longer from Eaſt to Weſt than from North to South, and covered with the Sky, as a Vault, in the Form of a Tent. Their Opinion appear'd to them by ſo much the more certain, as they believed it founded upon the Bible. But a very little Time before the Diſcovery of *America*, a Biſhop of *Avila* treated the Opinion of the Earth's globular Form as an Impiety, and an Abſurdity. At laſt Reaſon, and the Voyage of *Chriſtopher Columbus*, reſtored to the Earth its ancient ſpherical Form, which the *Egyptians* and *Chaldeans* had given it. People then paſſed from one Extreme to another; they believed the Earth a perfect Sphere, and that the Stars made their Revolution in a true Circle.

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* Some think the Vibrations at the Equator are fewer than near the Pole, becauſe of the denſer Medium there, by the Multitude of Vapours at the Equator from the Sun's Heat: for in the ſame Latitude the number of Vibrations change as the Medium in which

† Perhaps not the Number of them, but the Medium that reſiſts leſs or more.

Nevertheleſs, from the Moment that they began to be certain of the Earth's diurnal Rotation upon its own Axis, they ought to have judg'd from that alone, that a Form entirely ſpherical could not belong to it. They need only have conſidered, that ſuch a Rotation once in twenty four Hours muſt elevate the Waters of the Sea; that theſe Waters, being more elevated than the reſt of the Globe, would fall back upon the Land in the Region of the Equator, and overflow it: But the Waters have no ſuch Fall; therefore the ſolid Earth muſt be as much elevated as the Waters. This Reaſoning, ſo very ſimple, ſo natural, eſcaped the greateſt Genius's of that Time; a certain Proof of the Strength of Prejudice, that it did not permit even this ſlight Examination. They ſtill conteſted *Richer*'s Experiment: They pretended, that the Vibrations of our Pendulums were leſs frequent towards the Equator, for no other Reaſon but becauſe the Heat lengthened Metal: They perceived, that the Heat of the moſt ſcorching Summer, would lengthen an Iron Rod above thirty Feet long, about the eleventh Part of our Inch; but the Queſtion here was concerning a greater Alteration, perhaps even twice as great, in a Rod of little more than three Feet in Length.

Some Years after, Meſſ. *Deſhayes*, *Varin*, *Feuillée*, and *Couplet*, repeated the ſame Experiment of the Pendulum near the Equator: They found it neceſſary continually to ſhorten it, the nearer they came to the Line, tho' the Heats were often leſs under the Line itſelf,

ſelf, than at fifteen or twenty Degrees diſtance. This Experiment has been lately confirmed, by the Academicians who are at preſent in *Peru*; and they have juſt now informed us, that about *Quito*, in a Time when it freezed, they were obliged to ſhorten the Pendulum for Seconds about two Lines, or the ſixth Part of a Digit.

While they were thus diſcovering of new Truths, under the Line, Mr. *Picart*, in Conformity to the ſame Orders, gave to the World in 1669 a Meaſure of the Earth, by tracing over a ſmall Part of the Meridian of *France*. He did not indeed give ſo exact a Meaſure of the Earth, as he might have done, if he had meaſured the Degrees in *France* both towards the Pole and towards the Equator: But this Difference was too inſignificant to be taken notice of, among the Things that will now fall under our Conſideration.

Theſe Diſcoveries were neceſſary to found the Theory of Sir *Iſaac Newton*. We think ourſelves obliged here to inſert a certain curious Anecdote, concerning theſe Diſcoveries and this Theory, which will not be unprofitable in the Hiſtory of human Minds, and which will ſerve to diſcover the great Neceſſity of Exactitude in the Sciences, and with what Sincerity Sir *Iſaac* proceeded in his Search after Truth.

Anecdote concerning theſe Diſcoveries.

He had laid the Foundation of his admirable Syſtem of Gravitation ever ſince the Year 1666; but there was wanting, to reconcile this Syſtem with Truth in all its Parts, and above all to draw thoſe Concluſions from the Motion of the Moon which we are by and by to conſider; there was wanting, I ſay, a Demonſtration that the Degrees of Latitude were every one about 25 common *French* Leagues, that is, near 70 *Engliſh* Miles.

In the Year 1636, *Norwood*, an *Engliſh* Mathematician, had done that, in pure Curioſity, which the Benevolence of the *French* Miniſter cauſed *Picart* to undertake afterwards, in 1669: He had made the ſame Experiments concerning the Degrees of Latitude between *London* and *York*, in the North of *England*, as *Picart* made to the North of *Paris*, in a leſs Extent of Ground.

The Degrees of *Norwood* were found, within a Trifle, to conſiſt of 70 *Engliſh* Miles, or 25 *French* Leagues: This was preciſely the Meaſure that Sir *Iſaac Newton* had gueſs'd at by his Theory, and which alone could juſtify it.

But what will appear ſurprizing is, that in 1666, and even many Years after, Sir *Iſaac Newton* knew nothing of *Norwood*'s Meaſures, taken above 30 Years before the Misfortunes which had afflicted *England*, had been as fatal to the Sciences as to the State: *Norwood*'s Diſcovery was buried in Oblivion; every one kept to the erroneous Meaſure of the Pilots, who, in their random Computation, reckon'd only 60 Miles for a Degree of Latitude. And our Philoſopher being retired into the Country during the Plague in 1666, was not in the Way of getting any Information concerning *Norwood*'s Meaſures, and therefore ſtuck to the falſe Computation of 60 Miles.

It was by this erroneous Meaſure that he proceeded to enquire, as we have already ſaid, whether the ſame Power that occaſions the Gravitation of Bodies towards the Center of the Earth, was what held the Moon in her Orbit. He found himſelf far enough from thoſe Concluſions, which he could have drawn with a more exact Meaſure of the Earth, and for that Time abandon'd his Reſearch.

He reſumed it ſome Years after, upon the Meaſures of *Picart*, and ſtill farther confirmed himſelf in it in 1683, by the more exact Meaſures of *Caſſini*, *Lattiſe*, *Chazelles*, and *Varin*, who, encouraged by *Colbert*, traverſed a much larger Tract than *Picart*.

Theſe Academicians examined the Meridian even as far as *Auvergne*; but *Colbert* being dead, *Louvois*, who ſucceeded him in the Juriſdiction of the Academy, but not in his Taſte for the Sciences, interrupted a little this laborious Undertaking.

It was not till about that Time, that *Newton* became acquainted with the Operations of *Norwood*: He ſaw with Aſtoniſhment, that theſe Meaſures were the ſame with thoſe of *Picart* and *Caſſini*, with only this Difference, that *Norwood*'s Degree exceeded that of *Picart* 240 Fathoms, but ſurpaſſed that of *Caſſini* only eight. *Newton* attributed this ſmall Exceſs of 8 Fathom in a Degree to the Figure of the Earth, which he believed to be that of a Spheroid, depreſs'd or flatten'd towards the Poles; and he judg'd that *Norwood,* by drawing his Meridian in Regions more Northerly than thoſe of *France*, neceſſarily found his Degrees longer than thoſe of *Caſſini*, becauſe he ſuppoſed that part meaſured by *Norwood* to have a longer Curve. However that be, here follows the ſublime Theory which he drew from theſe Meaſures, and from the Diſcoveries of the great *Galileo.*

Theory drawn from theſe Diſcoveries.

The Gravity of Bodies upon our Globe, is in reciprocal proportion of the Squares of their Diſtances from the Center of the Earth: Thus, the more theſe Diſtances are increaſed, the more is Gravity diminiſhed.

The Power which is the cauſe of Gravity, depends not upon Whirlpools of ſubtile Matter, the Exiſtence of which is demonſtrably falſe.

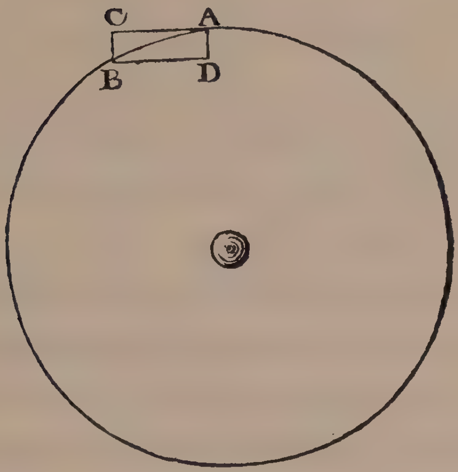
That Power, whatſoever it be, acts upon all Bodies, not according to their Surfaces, but in proportion to the Quantity of their Matter. If it acts at one Diſtance, it muſt act at all Diſtances: If it act in reciprocal Proportion of the Squares of theſe Diſtances, it muſt always act according to the ſame Proportion upon all known Bodies, when they are not at the Point of Contact, that is, let them be as near together as poſſible, without being joined.

If, according to this Proportion, the Power of Attraction, upon the Surface of our Globe, cauſes a Deſcent of 54,000 *Paris* Feet in 60 Seconds; a Body that ſhall be diſtant from the Center of the Earth about 60 of its Semi-diameters, by the ſame Rule will fall only fifteen *Paris* Feet in the ſame Time.

The ſame Power which occaſions the Gravitation of Bodies towards the Earth, directs the Moon in its Courſe round the Earth.

The Moon, in her mean Motion, is diſtant about 60 Semi-diameters of our Terreſtrial Globe from the Center of that Globe. Now by the Meaſures taken in *France*, we know how many Feet the Moon's Orbit contains; we know that in her mean Motion, ſhe deſcribes 187,961 *Paris* Feet in a Minute.

The Moon, in her mean Motion, is advanced from A to B: She has obeyed then, both the projectile Force, which directs her in the Tangent A, C, and the Power which wou'd make her deſcend according to the Line A, D, equal with B, C. Take away the Force which directs her from A to C, and



and there will remain a Force which may be eſtimated by the Line C, B. This Line C, B, is equal to the Line A, D: But it is demonſtrable that the Curve A, B, being 187,961 Feet, the Line A, D, or C, B, will be only fifteen: Therefore whether the Moon falls into B, or into C, it is here the ſame Thing; ſhe will have deſcended 15 Feet in a Minute from C to B; therefore ſhe will have deſcended 15 Feet in a Minute alſo from A to D. But in deſcending this Space in a Minute, ſhe will have travelled 3600 Times as far as a moveable Body upon the Earth would have travelled in the ſame Time: Now 3600 is juſt the Square of her

Diſtance; therefore the Gravitation which acts here upon all Bodies, acts alſo between the Earth and the Moon preciſely in the ſame Ratio of the Square of their Diſtances.

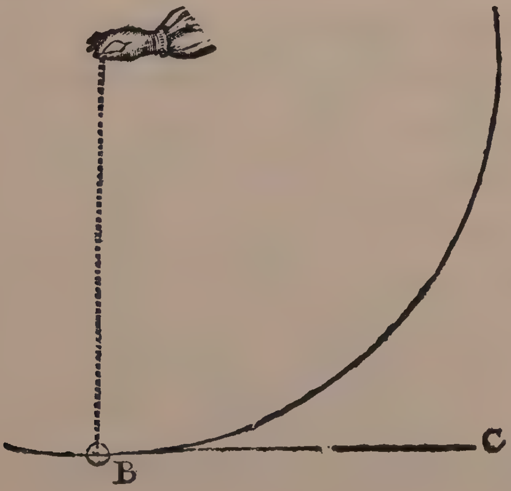
But if this Power which animates Bodies, directs the Moon in her Orbit, it muſt direct the Earth in its Orbit alſo; and the Effect which it produces upon the Planet of the Moon, it muſt produce alſo upon the Planet of the Earth: For this Power is every where the ſame; all the other Planets muſt be ſubject to it, and even the Sun alſo muſt experience its Law: And if there be no Motion of the Planets with Regard one to another, which is not the neceſſary Effect of this Power, it muſt then be confeſſed, that all Nature demonſtrates it: This is what we proceed to obſerve, in a more ample Manner.

CHAP. XIX.

That Gravitation and Attraction direct all the Planets in their Courſes.

How we ought to underſtand the Theory of Gravity according to Deſcartes.

ALMOST all the Theory of Gravity, according to *Deſcartes*, is founded upon this Law of Nature, that every Body which moves in a Curve Line, endeavours to move away from its Center in a right Line, which would touch the Curve in a Point. Such is the Sling, which eſcaping from the Hand at the Point B, would follow the Line B, C.



All Bodies, in turning with the Earth, endeavour thus to remove from the Center; but the ſubtile Matter, ſay they, making a much greater Effort, repells all other Bodies.

It is eaſy to perceive, that it could not be in the ſubtile Matter to make this greater Effort, and to remove itſelf from the Center of the pretended Vortex rather than other Bodies: On the contrary, it would be its Nature, (ſuppoſing it to exiſt) to make towards the Center of its Motion, and let the other Bodies, which are more compact and ſolid, move to the Circumference *. This is in Effect what happens upon a Table which is made to turn round, when in a Tube fixed thereon we put ſeveral Powers and Liquors, of Weights ſpecifically different: All the moſt ſolid and weighty Bodies remove from the Center, and all the lighteſt approach it. Such is the Law of Nature; and when *Deſcartes* made his pretended ſubtile Matter to circulate the Circumference of his Vortex, he began by violating that Law of Centrifugal Forces, which he laid down as his firſt

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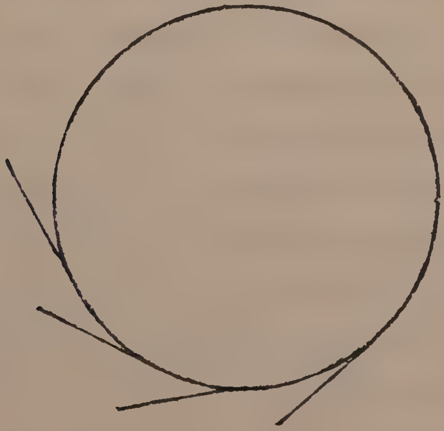
* *Deſcartes* ſuppoſed theſe Particles of ſubtile Matter to be moſt hard and ſolid.

Principle. It was to little purpoſe his imagining that God had created Dice * turning againſt one another; that the Rubbings of theſe Dice, which made his ſubtile Matter, diſperſing on all ſides, acquired thereby a ſwifter Motion; that the Center of a Vortex incruſtated itſelf, *&c.* Theſe Imaginations were far from rectifying his Error.

Without loſing more Time to combat theſe imaginary Beings, let us follow the mechanical Laws which operate in Nature. A Body which moves circularly, at every Point of the Curve which it deſcribes, takes a Direction that would remove it out of the Circle, by making it follow a right Line, in this Manner.



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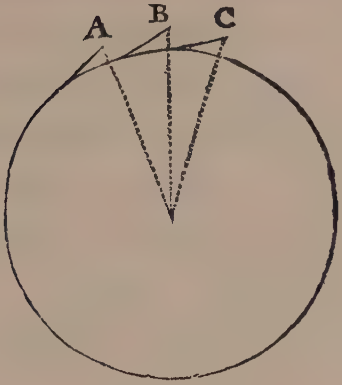
* He does not call them Dice but Particles of various Figures.

So far its true. But care muſt be taken that this Body do not thus remove from the Center, but by this other grand Principle: That every Body, being of itſelf indifferent with regard to Reſt and Motion, and having that *Vis inertiæ*, that Sluggiſhneſs which is an Attribute of Matter, follows neceſſarily the Line in which it is moved. Now every Body which turns round a Center, follows every Moment a right Line infinitely ſhort, which would become a right Line infinitely long, if it met with no Obſtacle. The Reſult of this Principle therefore, reduced to its juſt Value, is no more than this: That every Body which moves in a right Line, would always move in a right Line, if no Power acted upon it; there is another Power wanting then, to make it deſcribe a Curve: This other Power, therefore, by which it deſcribes a Curve, would make it fall every Moment to the Center, in Caſe the projectile Motion in a right Line was to ceaſe. In a Word, this Body would move, from Moment to Moment, to A, to B, to C, if freed from the latter Power.

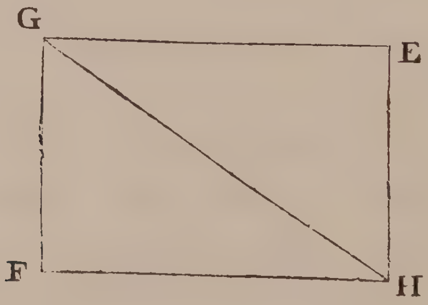


It would alſo, from Moment to Moment, fall from A, from B, from C, to the Center, if the other Power was wanting. The reaſon is, that its Motion is compoſed of two ſorts of Motions, of a projectile Motion in a right Line, and alſo of an imprinted Motion in a right Line, by the Centripetal Force, a Force by which it would fall to the Center. Thus even from the Inclination of the Body to deſcribe theſe Tangents A, B, C, it is demonſtrable that there is a Power which draws it from theſe Tangents, even at the Inſtant that it begins them. It is abſolutely neceſſary then, to conſider every Body that moves in a Curve, as being moved by two Powers; cne of which is, that which would make it deſcribe Tangents, and

What is meant by the Centrifugal and Centripetal Forces.

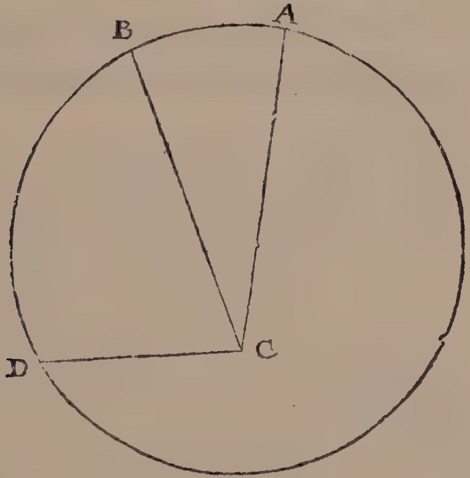
and which is called the Centrifugal Power, or rather the Power of reſting, of Inactivity, by which a Body always follows a right Line, if it meets with no Obſtruction; the other is the Power which draws the Body towards the Center, which is called the Centripetal, and is the true Power.

It is thus that a Body, moved according to the horizontal Line G, E, and according to the Perpendicular Line G, F, obeys theſe Powers every Moment, by paſſing along the Diagonal G, H.



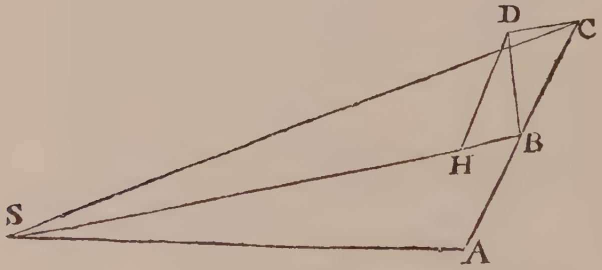
From the Eſtabliſhment of this Centripetal Force, there reſults at firſt Sight of this Demonſtration: That every Body which moves in a Circle, or in an Ellipſis, or in any Curve whatſoever, moves round a Center to which it tends.

It follows moreover; that this Body, what Portions of the Curve ſoever it may paſs over, will always deſcribe equal Areas in equal Times, both in its largeſt and ſmalleſt Arches. If, for Inſtance, a Body in one Minute deſcribes the Space A, C, B, containing an hundred Miles of Area, it will in two Minutes deſcribe the Space B, C, D, containing two hundred Miles.



This Law inviolably obſerved by all the Planets, and utterly unknown to Antiquity, was diſcovered about 150 Years ago by *Kepler*, who has merited the Name of *Legiſlator* in Aſtronomy, notwithſtanding his Philoſophical Errors. He could not, however, come at the Reaſon of this Rule, to which all the Celeſtial Bodies are ſubject. The extreme Sagacity of *Kepler* diſcovered the Effect, of which the Genius of *Newton* has found out the Cauſe.

I ſhall now give the Subſtance of *Newton*'s Demonſtration, which will eaſily be comprehended by every attentive Reader: For Men have a natural Geometry in their Minds, which makes them lay hold of Proportions, when they are not too complicated. The Demonſtration ſhall be found more at large in the Notes.



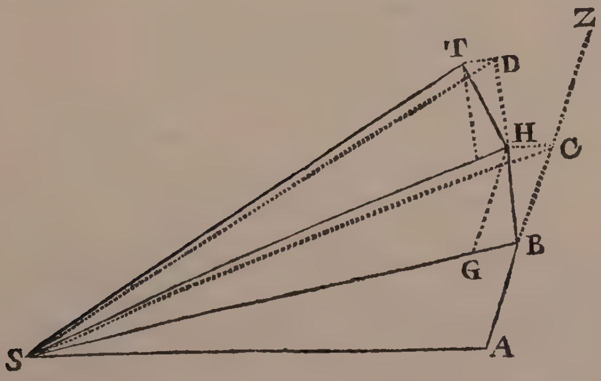
Let the Body A be moved to the Point B, in a very ſhort Space of Time. At the End of an equal Space of Time, a Motion equally continued (for there is here no Acceleration) would bring it to the Point C: But in B it finds a Power which draws it in the Line B, H, S.

B, H, S. It does not follow then, either the Road B, H, S, or the Road A, B, C: Draw this Parallelogram C, D, B, H; and then the Body being moved by the two Powers paſſes along the Diagonal B, D. Now this Line B, D, and this B, A, being ſuppoſed infinitely ſhort, make a Curve, *&c.* Therefore this Body neceſſarily moves in a Curve.

It

DEMONSTRATION.

That every moveable Body, drawn by a Centripetal Force, deſcribes in a Curve Line, equal Areas in equal Times (1).



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(1) All Bodies move in a uniform Motion, when there is no accelerating Force: Therefore the Body A, moved in a right Line in the firſt Space of time from A to B, will paſs

This Demonſtration proves that the Sun, and not the Earth, is the Center of the Univerſe.

It muſt ſurround equal Spaces in equal Times; for the Space of the Triangle S, B, A, is equal to the Space of the Triangle S, B, H: Theſe Triangles are equal; therefore theſe Areas are equal; therefore every Body which ſurrounds equal Areas in equal Times, in a Curve, makes its Revolution round the Center of the Forces towards which it tends; therefore the Planets tend towards the Sun, turn round the Sun, and not the Sun round the Earth. For by taking the Earth

paſs in the ſame Time from C to Z. Theſe Spaces being conceived equal, the Centripetal Force in the ſecond Time gives a certain Motion, and the Body, inſtead of going to C, goes to H. Now what Direction has it had different from that of B to C? Draw the four Lines, C, H; G, B; C, B; G, H; and you perceive the Body has followed the Diagonal of this Parallelogram B, H.

Now the two Sides of Parallelogram B, C; B, G; are in the ſame Plan as the Triangle A, B, S; therefore the Forces are directed towards G, S, and towards the right Line A, B, C, Z.

The Triangles, S, H, B; S, B, C; are equal, becauſe they are upon the ſame Baſis S, B, and between the Parallels, H, C; G, B; but S, B, A; S, C, B; are equal, having the ſame Baſe, and the ſame Height; therefore S, B, A; S, H, B; are equal alſo.

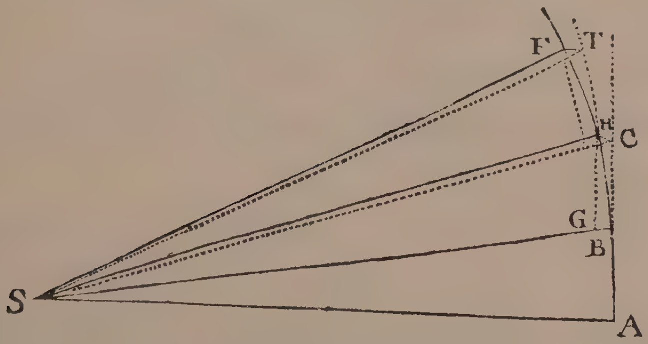
The ſame may be ſaid concerning the Triangles S, T, H; S, D, H; therefore all theſe Triangles are equal. Leſſen the Height to Infinity, the Body; in every Space of Time infinitely ſmall, will deſcribe the Curve, whoſe Lines all tend to the Point S; therefore in all theſe Inſtances, the Areas of theſe Triangles are proportional to the Times.

Earth for the Center, their Areas are found unequal in proportion to the Times; and in taking the Sun for the Center, theſe Areas are always found proportional to the Times; if you except only the ſmall Irregularities, cauſed by the Gravitation of the Planets themſelves.

The

DEMONSTRATION.

That every Body, deſcribing in a Curve equal Triangles round a Point, is moved round that Point by a Centripetal Force (2).



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(2) Let this Curve be divided into equal Parts infinitely ſmall, A, B; B, H; H, F; deſcribed in equal Times; let the Power be ſuppoſed to act at the ſame Points B, H, F; prolong A, B, to C, and B, H, to T; the Triangle S, A, B, will be equal to the Triangle S, B, H; for A, B, is equal to B, C; therefore S, B, H, is equal to S, B, C; therefore the Force in B, G, is parallel to that in C, H; but this Line B, G, parallel to C, H, is the Line B, G, S, tending

The better yet to underſtand what is meant by the Areas proportional to the Times, and to diſcover by Inſpection the Advantage you may draw from this Knowledge, conſider the Earth as carried in its Ellipſis round the Sun, S, its Center. When it goes from B to D, it encompaſſes as large a Space, as when it paſſes round the great Arch H, K: The Sector H, K, regains in Breadth what the Sector B, S, D, hath in Length. To make the Area of theſe Sectors equal in equal Times, the Body muſt paſs much ſwifter from H to K, than from B to D. Thus the Earth, and every Planet, moves ſwifter in its Perihelion, which is the neareſt Curve to the Sun, S, than in its Aphelion, which is the fartheſt Curve from the ſame Center S.

We

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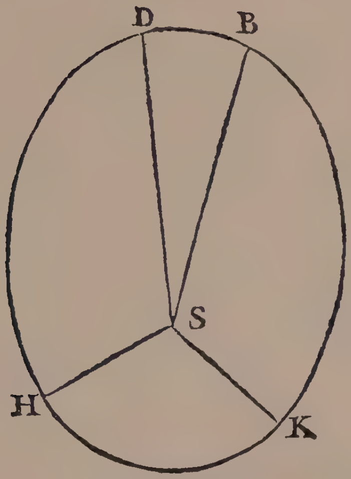
ing to the Center. The Body in H, is directed by the Centripetal Force along a parallel Line to F, T; in the ſame manner as in the Point B, it was directed by the ſame Force in a parallel Line to C, H: Therefore the Line parallel to F, T, will tend alſo towards S; therefore all Lines thus drawn, will tend to the Point S.

Conceive now to S, Triangles like thoſe above; the ſmaller thoſe Triangles above ſhall be, the more the Triangles to S, will approach to a phyſical Point, which Point S, will be the Center of the Forces.



We know then what is the Center of a Planet, and what Figure it deſcribes in its Orbit, by the Areas that it ſurrounds: We know that every Planet, when it is farther from the Center of its Motion, gravitates leſs towards that Center. Thus the Earth being nearer the Sun by a thirtieth Part, that is by a million of Leagues, during our Winter than during our Summer, is more attracted alſo in Winter, and paſſes ſwifter then by reaſon of its Curve: Thus we have eight Days and a half more Summer than Winter, and the Sun appears in the Northern Signs eight Days and a half more than in the Southern. Therefore ſince every Planet follows,

It is for the preceding Reaſons that we have more Summer than Winter.

lows, with regard to the Sun, its Center, that Law of Gravitation which the Moon experiences with regard to the Earth, and to which all Bodies are ſubject in falling upon the Earth, it is demonſtrable that this Gravitation, this Attraction, acts upon all Bodies that are known to us.

But another powerful Demonſtration of this Truth, is the Law that all the Planets follows reſpectively, in their Courſes, and in Diſtances: This is what it is now incumbent on us to examine.

CHAP. XX.

Demonſtration of the Laws of Gravitation, drawn from the Rules of Kepler: *That one of theſe Laws of* Kepler *demonſtrates the Motion of the Earth.*

Kepler's *Grand Rule.*

KEPLER found out another admirable Rule, of which I proceed to give an Example before I define it, in order to render the Thing more ſenſible and eaſy.

Jupiter has 4 Satellites, which make their Revolutions round him: The neareſt is diſtant 2 Diameters and five ſixths, from Jupiter's Body, which it ſurrounds in 42 Hours: The moſt remote makes its Revolution in 402 Hours, I would know how far diſtant this laſt Satellite is from the Center of Jupiter. To accompliſh this, I lay down the following Rule: As the Square of 42 Hours, the Revolution of the firſt Satellite, is to the Square of 402 Hours, the Revolution of the laſt; ſo is the Cube of 2 Diameters and $\frac{5}{6}$ to a fourth Term. This fourth Term being found, I extract its Cube Root, which Cube Root is found to be 12 $\frac{3}{2}$: Thus I learn that the fourth Satellite is diſtant from the Center of Jupiter 12 and $\frac{3}{2}$ of his Diameters.

I make uſe of the ſame Rule for all the Planets which revolve round the Sun, I ſay; Venus revolves in 224 Days, and the Earth in 365: The Earth is 30 millions of Leagues from the Sun, how many Leagues then muſt Venus be? I anſwer; as the Square of the Earth's Year is to the Square of the Year of Venus, ſo the Cube of the Earth's mean Diſtance is to a fourth Term, whoſe Cubic Root will be about 21,700,000 Leagues, which make the mean Diſtance of Venus from the Sun. I ſay the ſame with regard to the Earth and Saturn, *&c.*

This Law then is, that the Square of a Revolution of any one Planet, is always to the Square of the Revolutions of the other Planets, as the Cube of its Diſtance is to the Cubes of the Diſtances of the others, from the common Center.

Reaſons unworthy of a Philoſopher, given by Kepler *for this admirable Rule.*

Kepler, who found this Proportion, was very far from finding the Reaſon of it. Being leſs a good Philoſopher than an admirable Aſtronomer,

ſtronomer, he ſays (in his 4th Book of his Epitome) that the Sun hath a Soul; not an intelligent Soul, *Animum*; but a vegetant, active Soul, *Animam:* That in turning round upon his own Axis, he draws the Planets to himſelf; but that the Planets do not fall on the Sun, becauſe they alſo revolve upon their Axis. In making this Revolution, ſays he, they preſent to the Sun ſometimes a friendly, and ſometimes a hoſtile ſide; the friendly ſide is drawn, and the hoſtile ſide is repell'd; which produces the annual Courſes of the Planets in the Ellipſes.

It muſt be confeſſed, for the Humiliation of Philoſophy, that it was from this Reaſoning, ſo very unphiloſophical, that he concluded the neceſſity of the Sun's turning round on its Axis. Error accidentally conducted him to Truth; he conjectured the Rotation of the Sun on itſelf, above 15 Years before the Eyes of *Galileo* diſcovered it by the Help of Teleſcopes.

Kepler adds (in the ſame Book, p. 495) that the Maſs of the Sun, the Maſs of all the Ether, and the Maſs of the Spheres of the fix'd Stars, are perfectly equal; and that they are the three Symbols of the Holy Trinity.

The Reader, who, in reading over theſe Elements, ſhall have ſeen ſuch extravagant Dreams, on the ſide of ſuch ſublime Truths, in ſo great a Man as *Kepler*, in ſo profound a Mathematician as *Kircher*, ought not to be ſurprized at it: A Man may be a great Genius with regard to Calculations and Obſervations, and make a wrong uſe of his Reaſon on other Accounts: There are Minds which have need of Geometry to ſupport them, and which fall when they endeavour to proceed of themſelves. It is not ſurpriſing therefore that *Kepler*, in diſcovering theſe Aſtronomical Laws, did not find out the Reaſon of them.

The true Reaſon of this Law found by Newton.

This Reaſon is, that the Centripetal Force is preciſely in the reciprocal Proportion of the Square of the Diſtance from the Center of Motion, towards which theſe Forces are directed: This is what we are to obſerve attentively: In a Word, we ought throughly to underſtand, that the Law of Gravitation is ſuch, that every Body which approaches 3 Times nearer to the Center of its Motion, gravitates nine Times more; that if it removes three times farther diſtant, it will gravitate nine Times leſs; and that if it removes to an hundred Times the Diſtance, it will gravitate leſs 10,000 Times.

A Body moving circularly round a Center, gravitates then in the reciprocal Proportion of the Square of its actual Diſtance from the Center, as alſo in direct Proportion of the Quantity of its Matter: It is demonſtrable then, that it is Gravitation which occaſions its Revolution round the Center, ſince without this Gravitation it would remove from it, by deſcribing a Tangent. This Gravitation therefore will be found to act moſt ſtrongly upon a Body which revolves with moſt Velocity round the Center; and the farther this Body ſhall be removed, the more ſlowly will it turn, for then it will become the leſs ponderous.

It is for this Reaſon that the Earth, tho' 1170 Times leſs than *Jupiter*, does nevertheleſs weigh but 8 Times leſs than *Jupiter* upon the Body of the Sun; and this in direct Proportion of the Quantity of Matter in theſe Planets, and in reciprocal Proportion of the Squares of their Diſtances from the Sun.

Recapitulation of the Proofs of Gravitation.

Thus have we demonſtrated this Law of Gravitation, in Proportion to the Squares of Diſtances;

1. By the Orbit which the Moon deſcribes, and by her Diſtance from the Earth, or Center.

2. By the Courſe of every Planet round the Sun in an Ellipſis.

3. By the Compariſon of the Diſtances and Revolutions of all the Planets round the common Center.

Theſe Diſcoveries of Newton *and* Kepler *ſerve to demonſtrate that it is the Earth which turns round the Sun.*

It will not be ſuperfluous to remark, that this ſame Rule of *Kepler*, which ſerves to confirm the Diſcovery of *Newton* concerning Gravitation, confirms alſo the Syſtem of *Copernicus* concerning the Motion of the Earth. It may be ſaid that *Kepler*, by this ſingle Rule, has demonſtrated what was diſcovered before him, and opened the Way to thoſe Truths which were to be diſcovered in after Times. For as on the one Side it is demonſtrable, that if the Law of centripetal Forces had no Place, *Kepler*'s Rule would be impoſſible: On the other it is demonſtrable, that according to the ſame Rule, if the Sun turned round the Earth, we ought to ſay; As the

Revolution of the Moon round the Earth, is to the pretended annual Revolution of the Sun round the Earth ſo is the ſquare Root of the Cube of the Moon's Diſtance from the Earth, to the ſquare Root of the Cube of the Sun's Diſtance from the Earth. By this Calculation it would be found, that the Sun is only 510,000 Leagues from us; but it has been proved, that he is diſtant at leaſt about 30 Millions of Leagues: Thus the Motion of the Earth then has been ſtrictly demonſtrated by *Kepler*. Here follows another very ſimple Demonſtration, drawn from the ſame Reaſons.

Demonſtration of the Motion of the Earth, drawn from the ſame Laws.

If the Earth was the Center of the Sun's Motion, as it is of the Moon's, the Sun's Revolution would take up 475 Years, inſtead of one Year: For the mean Diſtance of the Sun from the Earth, is to the mean Diſtance of the Moon from the Earth as 337 is to one: Now the Cube of the Moon's Diſtance is 1, the Cube of the Sun's Diſtance is 38272753: Finiſh the Rule, and ſay, As the Cube 1 is to this Cube Number 38272753; ſo the Square of 28, which is the periodical Revolution of the Moon, is to a fourth Number:

You will find that the Sun would employ 475 Years, inſtead of one Year, in making its Revolution round the Earth: Which demonſtrates, that it is the Earth which turns.

It ſeems by ſo much the more proper to Place theſe Demonſtrations here, as there yet are Men deſtined for the Inſtruction of Youth, in *Italy*, in *Spain*, in *France*, and even in *England*, who doubt, or who affect to doubt, of the Earth's Motion.

It is proved then by *Kepler*'s Law, and by that of *Newton*, that every Planet gravitates towards the Sun, the Center of the Orbits which they deſcribe: Theſe Laws are fulfilled in the Satellites of Jupiter, with regard to Jupiter, their Center; in the Moons of Saturn, with regard to Saturn, and in our Moon, with regard to us: All theſe ſecondary Planets, which roll round their central Planets, gravitate alſo with their central Planets towards the Sun: Thus the Moon, which is drawn round the Earth by the centripetal Force, is at the ſame Time drawn by the Sun, round which ſhe makes her Revolution. There is no Variety in the Moon's Courſe, in her Diſtances from the Earth, in the Figure of her Orbit, ſometimes approaching to an Ellipſis, ſometimes to a Circle, *&c.* which is not from Gravitation, in proportion to her Diſtance from the Earth, and her Diſtance from the Sun.

If ſhe does not always, in her Orbit, exactly deſcribe equal Areas in equal Times, Sir *Iſaac Newton* has calculated all the Caſes where this Inequality muſt happen: They all depend on the Attraction of the Sun, which draws theſe two Globes in direct Proportion of their Maſſes, and in reciprocal Proportion of the Squares of their Diſtances. We ſhall ſee, in the next Chapter, that the ſmalleſt Variation of the Moon, is a neceſſary Effect of theſe united Powers.

CHAP. XXI.

New Proofs of Attraction. That the Inequalities of the Motion and Orbit of the Moon are neceſſarily the Effects of Attraction.

THE Moon hath only one equal Motion, that of Rotation round herſelf on her own Axis; and this is her only Motion which we cannot perceive: It is this Motion that preſents us always, within a Trifle, with the ſame Diſc of the Moon; ſo that while ſhe really turns round upon herſelf, ſhe appears not to turn at all, and to have only a ſmall Motion of Balancing, of Libration, which ſhe has not, but which all Antiquity attributed to her.

All her other Motions round the Earth are unequal, and ought ſo to be, if the Rule of Gravitation be true. The Moon, in her Monthly Courſe, is neceſſarily nearer the Sun in one certain Point, and at one certain Time of her Courſe: Now in this Point, and at this Time, her Quantity of Matter remains the ſame: Her Diſtance only being changed, the Attraction of the Sun ought to change in reciprocal Proportion of the Square of this Diſtance: The Courſe of the Moon ought then to change; ſhe ought to move ſwifter at certain Times, than the Attraction of the Earth alone occaſions her to move: Now by the Attraction of the Earth ſhe ought to paſs over equal Areas in equal Times, as you have already obſerv'd in Chap. 19.

One cannot help admiring the Sagacity with which Sir *Iſaac Newton* has cleared up all theſe Inequalities, and regulated the Courſe of this Planet, which remained a Secret before, after all the Reſearches of Aſtronomers: It is upon this Account, above all, that we may ſay:

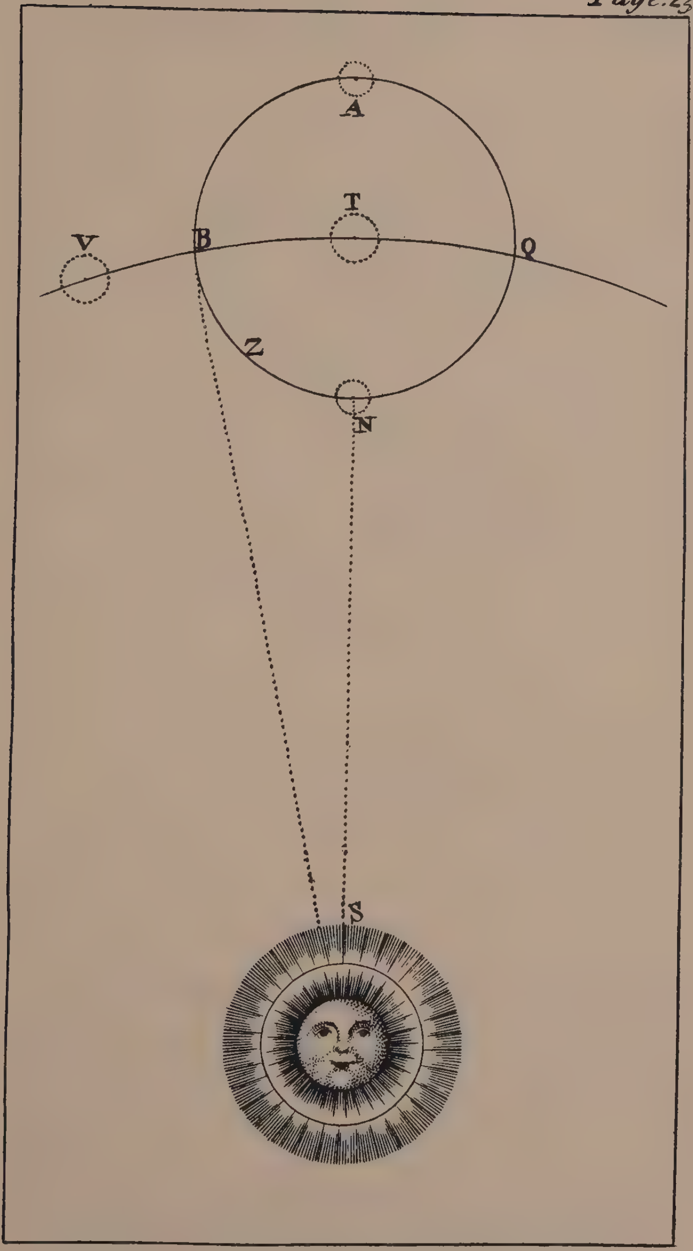
Nec propius fas eſt mortali attingere Divos.

Proof by an Example.

Among the Examples that may be choſen, let us take this: Let A be the Moon; A,B,N,Q, the Orbit of the Moon; S, the Sun; B, the Place of the Moon in her laſt Quarter.

She is now manifeſtly at the ſame Diſtance from the Sun as the Earth. The Difference of the Obliquity of her Line of Direction to the Sun being counted for nothing, the Gravitation of the Earth and of the Moon towards that Luminary is apparently the ſame. The Earth, however, advances in its annual Courſe from T to V, and the Moon in her Monthly Courſe advances to Z. Now in Z it is manifeſt that ſhe is more drawn by the Sun, S, to which ſhe finds herſelf nearer than the Earth: Her Motion then will be accelerated from Z towards N, and the Orbit that ſhe deſcribes will be changed: But how will it be changed? In being flattened a little, in approaching more to a right Line from Z towards N. Thus, from Moment to Moment, Gravitation changes the Courſe and Form of the Ellipſis, in which this Planet moves.

By the ſame Reaſon the Moon ought to ſlacken her Courſe, and to change again the Figure of the Orbit that ſhe deſcribes, when ſhe returns from her Conjunction N, to her firſt Quarter Q; for ſince from her laſt Quarter ſhe accelerated her Courſe, by flattening the Curve towards N, her Conjunction; ſhe ought to ſlacken the ſame Courſe by ſwelling out the Curve, in returning from her Conjunction to her firſt Quarter.


A
T
V
B
Q
Z
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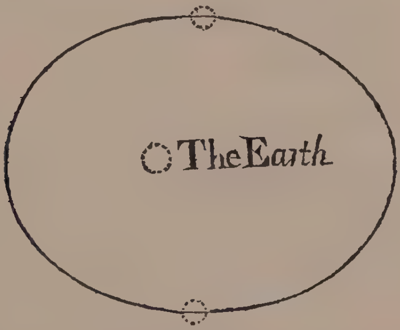
S

But when the Moon aſcends from this firſt Quarter towards her Full, A, ſhe being then farther from the Sun, is leſs attracted by it, and gravitates more towards the Earth. Then the Moon accelerating her Motion, the Curve that ſhe deſcribes is again flattened a little, as in her Conjunction. And this is the only Reaſon for which the Moon is farther from us in her Quarters, than in her Conjunction and Oppoſition. The Curve that ſhe deſcribes is a kind of Oval, approaching to a Circle, almoſt in this Manner.



Thus the Sun then, to which ſhe approaches, or from which ſhe recedes at every Inſtant, muſt at every Inſtant vary the Courſe of this Planet.

The Inequalities of the Moon's Courſe all cauſed by Attraction.

She hath alſo her Apogæon and her Perigæon, her greateſt and her leaſt Diſtance from the Earth: But the Points, the Places of this Apogæon and Perigæon, muſt neceſſarily change.

She hath her Nodes, that is to ſay, the Points where the Orbit ſhe deſcribes meets preciſely the Orbit of the Earth: But theſe Nodes, theſe Points of Interſection, muſt alſo continually vary.

She hath her Equator, inclined to the Equator of the Earth: But this Equator, ſometimes more and ſometimes leſs attracted, muſt likewiſe change its Inclination.

She follows the Earth notwithſtanding all theſe Varieties, and accompanies it in its annual Courſe: But the Earth, in this Courſe, is found to be a Million of Leagues nearer the Sun in Winter than in Summer. What is the Conſequence of this, independent of all theſe other Variations? The Attraction of the Earth acts more fully upon the Moon in Summer, and then the Moon finiſhes her Monthly Courſe a little ſooner: But, on the contrary, in the Winter, the Earth itſelf being more attracted by the Sun, and moving with greater Velocity than in Summer, ſuffers the Motion of the Moon to diminiſh, and her Winter Months to be a ſmall Matter longer than her Summer ones. The little that we ſay of them, may ſuffice to give a general Idea of theſe Changes.

If any one ſhould here ſtart the Difficulty, which I have heard ſometimes propoſed, why the Moon, when ſhe is moſt attracted by the Sun, does not fall upon that Luminary? We have only to conſider for the preſent, that the Force of Gravitation, which directs the Moon round the Earth, is only diminiſhed here by the Action of the Sun *: We ſhall ſee farther in the Article of Comets, why a Body which moves in an Ellipſis, and approaches its Center, nevertheleſs does not impinge upon this Center.

Deduction from theſe Truths.

From theſe Irregularities of the Lunar Courſe, cauſed by Attraction, you will reaſonably conclude, that no two Planets ſufficiently near, ſufficiently large to act upon one another ſenſibly, can at any Time move round the Sun in Circles, or even in Ellipſes abſolutely regular. Thus the Curves deſcribed by Jupiter and Saturn, for Example, are ſubject to ſenſible Variations, when theſe Pla-

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[*] The Diſtance of the Moon from the Sun being vaſtly greater than from the Earth, ſhe is attracted as much by the Earth as to overcome that of the Sun, and to balance the centrifugal Force.

nets are in Conjunction; when, being the neareſt that poſſibly they can be to each other, and the fartheſt from the Sun, their mutual Action augments, and that of the Sun on them diminiſhes.

Gravitation is not the Effect of the Planets Courſes, but their Courſes are the Effect of Gravitation.

This Gravitation then, augmented and leſſened in proportion to the Diſtances, neceſſarily aſſigns an irregular elliptical Figure for the Way of the greateſt Part of the Planets: Thus the Law of Gravitation is not the Effect of the Planetary Courſes, but the Orbits which the Planets deſcribe are the Effect of Gravitation. If this Gravitation was not, as it really is, in reciprocal Proportion of the Squares of Diſtances, the preſent Order of the Univerſe could not ſubſiſt.

If the Satellites of Jupiter and Saturn make their Revolution in Curves which approach nearer to a Circle, it is becauſe being very near the great Planets that are their Center, and very far from the Sun, the Action of the Sun cannot change the Courſe of theſe Satellites, as it changes that of our Moon. It is manifeſt then, that Gravitation, the Name of which alone ſeems ſuch a ſtrange Paradox, is a neceſſary Law in the Conſtitution of the

World: So true, very often, is a thing that hardly has the Appearance of Probability!

Let us remember here, how abſurd the Opinion formerly ſeemed, that the Earth was not ſpherical; and yet it has been proved, that the Earth cannot have an entirely ſpherical Form; The like may be ſaid concerning Gravitation.

There is not at preſent any good Naturaliſt, who does not acknowledge both *Kepler*'s Rule, and the Neceſſity of admitting a Gravitation ſuch as *Newton* has proved: But there are yet ſome Philoſophers attached to their Vortices of ſubtile Matter, who would willingly reconcile theſe imaginary Vortices with theſe other demonſtrable Truths.

This Gravitation, this Attraction, may be a firſt Principle eſtabliſhed in Nature.

We have already ſeen, how far theſe Vortices are from being probable: But this Gravitation itſelf, does it not furniſh a freſh Demonſtration againſt them? For ſuppoſing that theſe Vortices exiſted, they could not turn round a Center but by the very Laws of this Gravitation. We muſt have recourſe to Gravitation, as the Cauſe of theſe Vortices, and not to the pretended Vortices as the Cauſe of Gravitation.

If at laſt, being forced to abandon their imaginary Vortices, theſe Gentlemen are reduced to ſay that this Gravitation, this Attraction, depends on ſome other Cauſe, or ſome other ſecret Property of Matter; either that Property will itſelf be the Effect of ſome other Property unknown, or elſe it will be a primary Cauſe, a firſt Principle eſtabliſhed by the Author of Nature: Now why may not the Attraction of Matter itſelf be this firſt Principle*?

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* Some tell us that Matter being purely paſſive cannot be an active Principle, elſe it might move itſelf as well as draw; we muſt then ſay it is ſo, becauſe God would have it ſo, and ſo it's not an intrinſic eſſential Property; for the Sun repells the Light from it, and the Particles of Air one another in Rarefaction: Thus God the General in the Univerſe gives different Orders to different Bodies.

CHAP. XXII.

New Proofs and new Effects of Gravitation. That this Power is in every Particle of Matter. Diſcoveries dependent on this Principle.

WE may collect from all theſe Notions, that the Centripetal Force, Attraction, Gravitation, is the indubitable Principle of the Planetary Courſes *, of the Deſcent of all Bodies, and of that Ponderoſity which we experience in Bodies. This Centripetal Force, this Attraction, is not, nor can be, the ſimple Power of one Body to draw another to itſelf: We ſhall conſider it here as a Power, from which reſults the Motion round a Center: This Power cauſes the Sun to gravitate towards the Center of the Planets, as the Planets gravitate towards the Sun, and draws the Earth towards the Moon, as well as the Moon towards the Earth.

One of the primitive Laws of Motion, is yet a fuller Demonſtration of this Truth.

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* It is in Conjunction with the Projectile Force.

This Law is, that Re-action is equal to Action: Thus if the Sun gravitates on the Planets, the Planets gravitate on the Sun; and we ſhall ſee at the Beginning of the following Chapter, in what manner this great Law operates.

Now this Gravitation acting neceſſarily in direct proportion of the Quantity of Matter, and the Sun being about 760 Times as maſſy as all the Planets put together (without reckoning the Satellites of Jupiter, and the Ring and Moons of Saturn) it follows that the Sun muſt be their Center of Gravitation, and conſequently, that they muſt revolve round that Luminary.

A general and important Remark concerning the Principle of Attraction.

Let us carefully remark, that, when we ſay, the Power of Gravitation acts in direct Proportion of the Quantities of Matter, we always underſtand that this Power of Gravitation acts ſo much the more ſtrongly on a Body, as this Body has a greater number of Particles; and we have demonſtrated it, in ſhewing that a Straw deſcends as ſwiftly in the Machine purged of Air, as a Pound of Gold. We have ſaid (making Allowance only for the ſmall Reſiſtance of the Air) that a leaden Ball, for Example,

ample, falls fifteen Feet in one Second upon the Surface of the Earth: We have demonſtrated, that this ſame Ball would fall only fifteen Feet in a Minute, if it was removed from the Earth, as the Moon is, 60 of the Earth's Semidiameters: Therefore the Power of the Earth upon the Moon is to the Power that it would have upon a leaden Ball tranſported to the Elevation of the Moon, as the ſolid Body of the Moon would be to the ſolid Body of this Ball. It is in this Proportion that the Sun acts upon all the Planets; he draws Jupiter and Saturn, and the Satellites of Jupiter and Saturn, in direct proportion of the Quantity of ſolid Matter that is in each of theſe primary and ſecondary Orbs.

From hence flows an inconteſtible Truth; that this Gravitation is not only in the whole Maſs of every Planet, but in every Particle of that Maſs; and that thus there is not an Atom of Matter in the Univerſe, but what is inveſted with this Property.

Gravitation, Attraction, is equally in all the Particles of Matter.

From among the Methods in which *Newton* has demonſtrated that Gravitation is equally in every Atom, we will chuſe here the moſt ſimple. If all the Parts of a Globe had not equally this Property, if there were ſome weaker and ſome ſtronger Particles, a Planet, in turning upon its own Axis, would neceſſarily preſent ſometimes weaker and ſometimes ſtronger ſides at the ſame Diſtance: Thus the ſame Bodies, on all poſſible Occaſions, would experience at an equal Diſtance, now one Degree of Gravitation, now another: The Law of reciprocal Proportion of the Squares of Diſtances, and the Law of *Kepler*, would be always inverted, or proved not to ſubſiſt: Therefore there is not, in all the Planets, any one Particle of Matter that gravitates more than another.

Here follows another Demonſtration of the ſame Truth. If there were Bodies in which this Property was different, ſome Bodies would fall more ſlowly, others more ſwiftly, in the empty Air-Pump. But all Bodies fall in the ſame Time; and all Pendulums of equal Length, whether of Gold, of Silver, of Iron, of Maple-wood, or of Glaſs, make equal Vibrations in the Air in equal Times: Therefore all Bodies have this Property of Gravitation preciſely in the ſame Degree, that is, preciſely in proportion to their

Maſs; ſo that Gravitation acts as a hundred upon a hundred Atoms, and as ten upon ten Atoms.

From Truth to Truth the human Mind riſes inſenſibly to ſuch ſublime Points of Knowledge, as ſeem to be entirely out of its Sphere.

A bold and admirable Calculation of Newton.

Sir *Iſaac Newton* has ventured, by the help only of the Laws of Gravitation, to calculate what muſt be the Weight of Bodies in other Globes beſides this which we inhabit; what the ſame Body, for Inſtance, which we here call a Pound, muſt weigh in the Moon, in Saturn, in the Sun: And as theſe different Weights depend directly on the Quantity of Matter in theſe Globes, it was neceſſary to calculate what that Quantity is. Let it not be ſaid, after this, that Gravitation, that Attraction is an occult Quality: Let not any one dare to call by this Name an univerſal Law, which leads to ſuch aſtoniſhing Diſcoveries!

There is nothing more eaſy than to know the Magnitude of any Celeſtial Orb, from the Moment that its Diameter is known: For the Product of the Circumference of the great Circle by the Diameter, gives the Surface of the Globe; and the third of the Product of this Surface by the Semi-diameter, ſhews the Magnitude.

But by knowing the Magnitude, we learn nothing at all of the Quantity of Matter which this Orb contains. This too may be known, by that admirable Diſcovery of the Laws of Gravitation.

How to know the Quantity of Matter in a Globe, and what the ſame Bodies weigh upon diſtant Globes.

1ſt, *When the* Denſity, *or* Quantity of Matter *of any Globe is mentioned, we ſuppoſe that the Matter of this Globe is homogeneous; for Example, that every Cubic Foot of this Matter is equally weighty.*

2dly, *Every Globe attracts in direct proportion of the Quantity of its Maſs: Thus, all things equal, a Globe which ſhall have* 10 *Times more Matter, will attract, at the ſame Diſtance,* 10 *Times more ſtrongly than one of but a* 10*th Part of the Subſtance.*

3dly, *It is abſolutely neceſſary to conſider the Magnitude of the Circumference of the Globe under Examination: For the larger the Circumference, the more the Diſtance from the Center augments, and it attracts in reciprocal Ratio of the Square of this Diſtance. If the Diameter of the Planet* A, *for Inſtance, is four Times larger*

larger than that of the Planet B, *both having an equal Quantity of Matter; the Planet* A, *will attract Bodies to its Surface* 16 *Times leſs than the Planet* B, *and that which weighs a Pound upon the Planet* A, *will weigh* 16 *Pounds upon the Planet* B.

4thly, *It muſt be known, above all, in how long Time the Bodies attracted by the Globe, whoſe Denſity we enquire after, make their Revolution round this Globe: For, as we have ſeen in* Chap. XIX. *every Body circulating round another, gravitates the more, the more ſwiftly it turns: Now it muſt be for one of theſe two Reaſons that it gravitates the more, either becauſe it approaches nigher the Center which attracts it, or becauſe this attracting Center contains more Matter. If I would know, therefore, the Denſity of the Sun, in compariſon with the Denſity of the Earth, I muſt compare the Time of the Revolution of ſome Planet, as Venus, round the Sun, with the Courſe of the Moon round our Earth, and the Diſtance of Venus from the Sun, with the Diſtance of the Moon from the Earth.*

5thly, *I proceed thus. The Quantity of the Sun's Matter, in compariſon with that of the Earth,*

Earth, is as the Cube of the Diſtance of Venus from the Center of the Sun to the Cube of the Moon's Diſtance from the Center of the Earth, (taking the Diſtance of Venus from the Sun to be 257 *Times as great as that of the Moon from the Earth) and alſo in reciprocal Proportion of the Square of the periodical Revolution of Venus round the Sun, to the Square of the periodical Revolution of the Moon round the Earth.*

This Operation being made, ſuppoſing always that the Sun is in Magnitude to the Earth as a Million to one, and counting ſtill in round Numbers, you will find that the Sun, a Million of Times larger than the Earth, contains only 250,000 *Times as much Matter, or thereabouts.*

This being ſuppoſed, I would know what Proportion is found between the Force of Gravitation on the Surface of the Sun, and that ſame Force on the Surface of the Earth; I would know, in a Word, how much that Body which weighs a Pound here, would weigh upon the Sun.

To come at this, I ſay; the Force of this Gravitation depends directly on the Denſity of the

the attracting Globes, and on the Diſtance of the Center of theſe Globes from the ponderous Bodies on their Surface. Now the Diſtance between the Bodies and the Center, is preciſely the Semi-diameter of the Globes: But the Semi-diameter of the Globe of the Earth is to that of the Sun as 1 *to* 100, *and the reſpective Denſity of the Earth is to that of the Sun as* 4 *to* 1: *Then I ſay; as* 100, *the Semi-diameter of the Sun, multiplied by* 1, *is to* 4, *the Denſity of the Earth, multiplied by* 1; *ſo is the Weight of Bodies upon the Surface of the Sun to the Weight of the ſame Bodies upon the Surface of the Earth. This proportion between* 100 *and* 4, *being reduced to other Terms, is as* 25 *to* 1: *A Pound, therefore, weighs* 25 *Pounds upon the Surface of the Sun; which anſwers my Queſtion.*

I have ſuppoſed here the reſpective Denſities of the Earth and Sun to be as 4 *to* 1; *but this is not the exact Proportion: The Weight of Bodies, therefore, upon the Surface of the Sun, is to that of Bodies upon the Earth, not as* 25, *but as* 24 *to* 1.

We cannot have the ſame Notions concerning all the Planets; for thoſe which have no Moons, no Satellites, being deſtitute of Orbs of Compariſon, cannot be ſubject to our Reſearches: Thus we know not the Proportion of Gravity, that ſubſiſts between Mercury, Mars, Venus, and us, but we know that of the other Planets.

I proceed to give a ſhort Theory of all our Planetary World, ſuch as the Diſcoveries of Sir *Iſaac Newton* make it appear to us. Thoſe who would become Maſters of the more profound Reaſon of theſe Calculations, may read Sir *Iſaac* himſelf, or Mr. *Gregory*, or Mr. *Graveſande*. The Reader need only be informed, that in following the Proportions diſcovered by *Newton*, we have kept to the Aſtronomical Calculation of the *Paris* Obſervatory. Whatever the Calculation may be, the Proportions and Proofs are the ſame.

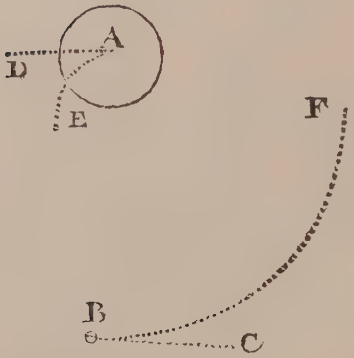
CHAP. XXIII.

The Theory of our Planetary World.

The SUN.

THE Sun is the Center of our Planetary World, and ought neceſſarily to be there. We do not mean by this, that the middle Point of the Sun is preciſely the Center of the Univerſe; but that the central Point towards which our Univerſe gravitates, is neceſſarily in the Body of that Luminary, and all the Planets, having once received their projectile Motion, muſt continually turn round this Point, which is in the Sun. We prove it thus.

Let the greateſt of theſe two Globes, A, and B, repreſent the Sun, and the leaſt any Planet whatſoever. If they are both abandoned to the Law of Gravitation, and free from all other Motion, they will be attracted in direct Proportion of their Quantity of Matter; they will be determined towards one another in a ſtraight Line; and A, being a Million of Times larger than B, will force B to move towards it a Million of Times faſter than A will move towards B.



Demonſtration of the Earth's Motion round the Sun, drawn from the Law of Gravitation.

But let them both have a projectile Motion, in proportion to their Maſſes*, the Planet in the Line B, C, the Sun in the Line A, D, and then the Planet is under two Forces; it tends in the Line B, C, and gravitates at the ſame time towards the Sun in the Line A, B: It will therefore deſcribe the Curve B, F; and the Sun, in like manner, will follow the Line A, E; and both, gravitating towards each other, will turn round a common Center: But the Sun ſurpaſſing the Earth in Magnitude a Million of Times, and the Curve A, E, which he will deſcribe, being a Million of Times leſs than that which the Earth deſcribes, this common Center is neceſſarily near the Middle of the Sun.

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* The Sun can have no projectile Force, not from the Earth; for the Earth hath it not from the Sun, but from an intelligent Being.

It is hereby again demonſtrated, that the Earth and the Planets turn round this Luminary: And this Demonſtration is by ſo much the more beautiful and ſtrong, as it is entirely independent on Obſervation, and founded upon the primordial Mechaniſm of the World.

The Sun's Magnitude.

If we make the Diameter of the Sun equal to 100 Diameters of the Earth, and if conſequently, the Sun ſurpaſſes the Earth a Million of Times in Magnitude; it will follow, he is 760 times larger than all the Planets together, leaving out the Satellites of Jupiter and Saturn's Ring. He gravitates towards the Planets, and the Planets too gravitate towards him; it is this Gravitation that makes them circulate, by drawing them from a Tangent *; and the Attraction which the Sun exerciſes upon them, ſurpaſſes that which they exerciſe upon him, as much as he ſurpaſſes them in Quantity of Matter. Never loſe Sight of this Truth, that reciprocal Attraction is nothing but the Law of moveable Bodies, all gravitating, and all turning round one common Center.

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* Nothing determines the Sun to move in a Tangent.

He turns on his own Axis round the common Center of the Planetary World.

The Sun then turns round this common Center, that is, upon his own Axis, in 25 Days and $\frac{1}{2}$. His middle Point is always a little diſtant from this common Center of Gravity, and his Body removes from it in proportion as ſeveral Planets in Conjunction attract him towards them: But if all the Planets were on one Side, and the Sun on the other, the common Center of Gravity would hardly be out of the Sun's Body; their united Forces being ſcarcely ſufficient to diſorder and remove the Sun one entire Diameter.

He continually changes Place.

He really changes Place then every Moment, according as he is more or leſs attracted by the Planets; and this little Approach of the Sun re-eſtabliſhes that Diſorder which the Planets operate on one another: Thus the continual Irregularity of this Luminary preſerves the Order of Nature.

Tho' he ſurpaſſes the Earth in Magnitude a Million of Times, he contains not a Million of Times as much Matter, as was before ſaid.

If he was actually a Million of Times more ſolid, more compact than the Earth, the Order of the World would not be what it now is: For the Revolutions of the Planets, and their Diſtances from their Center, depend on their Gravitation, and their Gravity is in direct Proportion of the Quantity of Matter in the Globe which is their Center: Therefore if the Sun ſurpaſſed our Earth and our Moon in ſolid Matter to ſuch a great Exceſs, the Planets would be much more attracted, and their Ellipſes much leſs regular, than they are at preſent.

In the ſecond Place, the Matter of the Sun cannot be in proportion to his Magnitude; for his Globe being all on fire, its Rarefaction is neceſſarily very great, and the Matter is leſs in proportion as the Rarefaction is greater.

His Denſity.

By the Laws of Gravitation it appears, that the Sun contains but 250,000 Times as much Matter as the Earth: Now the Sun, a Million of Times larger, being but the fourth Part of a Million more material than the Earth; the Earth, a Million of Times leſs, has in Proportion four Times as much Matter as the Sun, and is four Times as denſe.

The ſame Body, according to this Computation, which weighs a Pound upon the

Surface of the Earth, would weigh 25 Pounds upon the Surface of the Sun: But the true Proportion is only of 24 to 1, becauſe the Earth is not in Effect four Times as denſe as the Sun, and becauſe the Diameter of the Sun ſurpaſſes that of the Earth only 95 Times and an half.

In what Proportion Bodies deſcend upon the Sun.

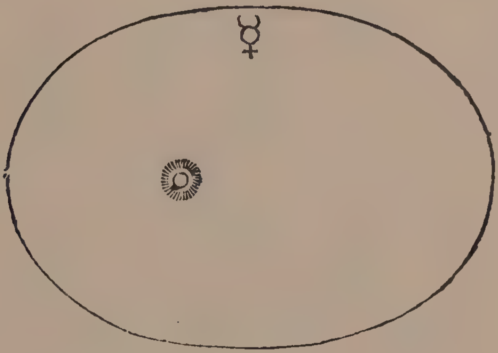
The ſame Body which deſcends here 15 Feet in the firſt ſecond, would deſcend about 350 Feet upon the Surface of the Sun, all other things being equal.

The Sun loſes daily, according to Sir *Iſaac*, a little of his Subſtance, and would be in the Revolution of many Ages reduced to nothing, if the Comets, which from Time to Time impinge on his Sphere, did not ſerve to repair his Loſſes; for every thing in the Univerſe alters, and is repaired.

MERCURY.

From the Sun to the Diſtance of eleven or twelve Millions of *French* Leagues, or thereabouts, there does not appear any Globe.

At 11 or 12 Millions of Leagues from the Sun is Mercury, in his mean Diſtance. This is the moſt excentric of all the Planets; he turns in an Ellipſis, which puts him in his Perihelion near a third Time nearer the Sun than in his Aphelion: Such is, within a Trifle, the Curve that he deſcribes.



Mercury is almoſt 27 Times leſs than the Earth: He turns round the Sun in 88 Days, which conſtitute his Year.

Newton's *Idea concerning the Denſity of Mercury.*

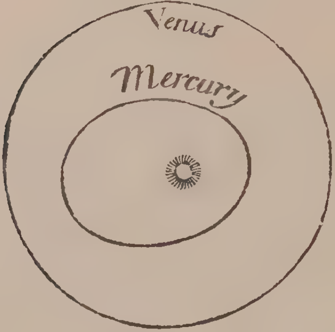
His Revolution upon his own Axis, which makes his Day, is unknown; nor can either his Weight, or his Denſity, be aſcertained. We only know, that if Mercury be an Earth exactly like ours, the Matter of its Globe muſt be about 8 Times more denſe than ours: Otherwiſe, every thing there would be in ſuch a Degree of Effervеſcence, as would deſtroy Animals of our Species in an Inſtant, and cauſe all Matter of the Conſiſtence of the Waters on our Globe to evaporate.

Here follows a Proof of this Aſſertion. Mercury receives about 7 Times more Light than we, in Proportion to the Square of Diſtances, becauſe it is about $2\frac{2}{3}$ Times nearer the Center of Light and Heat; it is therefore 7 Times more ſuffocated, all things being equal. Now upon our Earth the great Heat of Summer being augmented 7 or 8 Times, makes the Water boil up immediately in large Bubbles: Therefore it is neceſſary that every thing ſhould be about 7 Times more denſe than it is, to reſiſt 7 or 8 Times as much Heat as the moſt ſcorching Summer produces in our Climates: Therefore Mercury ought to be at leaſt 7 Times more denſe than our Earth, to make it poſſible for the ſame Things as ſubſiſt in our Earth to ſubſiſt in the Globe of Mercury, all things being equal. Finally, if Mercury receives about 7 Times more Rays than our Globe, becauſe it is about $2\frac{2}{3}$ Times nearer the Sun; by Parity of Reaſon, the Sun appears in Mercury 7 Times larger than on our Earth.

VENUS.

After Mercury is Venus, at between 21 and 22 Millions of Leagues from the Sun in its mean Diſtance: It is as large as the Earth, and its Year conſiſts of 224 Days. We do not yet know the Length of its Day, that is, of its Revolution on its own Axis. Very great Aſtronomers believe this Day to be only 23 Hours; others lengthen it to 25 of our Days. There have not hitherto been made any Obſervations, ſufficiently certain to ſhew on which Side is the Error: But this Error, wherever it be, can be only a Miſtake of the Eyes, an Error of Obſervation, and not of Judgment.

The Ellipſis which Venus deſcribes in its Year, is leſs eccentric than that of Mercury: One may form to himſelf ſome Idea of the Way of theſe two Planets round the Sun, from the ſubſequent Figure.



***Prediction* of Copernicus *concerning the Phaſes of* Venus.**

It is not foreign to our Purpoſe to remark here, that Venus and Mercury have different Phaſes with regard to us, as well as the Moon. *Copernicus* was formerly reproached, for that theſe Phaſes ought to appear in his Syſtem; which it was concluded was falſe, becauſe no ſuch Phaſes could be perceived. If Venus and Mercury, ſaid his Antagoniſts, turn round the Sun, and we turn in a greater Circle, we ought to ſee Venus and Mercury, ſometimes full, ſometimes increaſing, *&c.* but this is what we have never ſeen. It is nevertheleſs what really happens, anſwered *Copernicus*, and what you will ſee hereafter, if ever you find Means to make your Sight more perfect. The Invention of Teleſcopes, and the Obſervations of *Galileo*, conſpired ſoon after to accompliſh the Prediction of *Copernicus.*

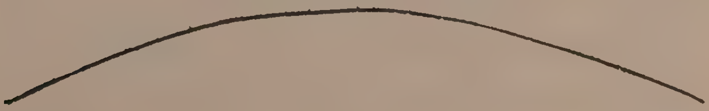
pernicus. As to other Particulars, nothing certain can be ſaid concerning the Quantity of Matter in Venus, or the Ponderoſity of Bodies on this Planet.

The EARTH.

Next after Venus is placed the Earth, at 30 Millions of Leagues from the Sun, or thereabouts, at leaſt in its mean Diſtance.

It is near a million of Times leſs than the Sun, towards which it gravitates, and round which it revolves in an Ellipſis in 365 Days, 5 Hours, and 48 Minutes; travelling at leaſt 180 Millions of Leagues every Year. The Ellipſis which it deſcribes is very irregular, on Account of the Moon's Action upon it; ſo that while the common Center of the Earth and the Moon deſcribes a true Ellipſis, the Earth actually deſcribes the following Curve every Lunar Revolution.

The inſenſible Curve which the Earth deſcribes each Lunation.



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What is the Cauſe of the Diurnal Rotation of the Earth.

The Earth's Rotation upon its own Axis from Weſt to Eaſt conſtitutes its Day of 23 Hours, 56 Minutes. This Motion is not the Effect of Gravitation. It ſeems impoſſible here, in particular, to have Recourſe to that ſufficient Reaſon ſpoken of by that great Philoſopher *Leibnitz*. It is abſolutely neceſſary to confeſs, that the Planets and the Sun might as well turn from Eaſt to Weſt: Therefore we muſt allow, that this Rotation from Weſt to Eaſt is an Effect of the Free-will of the Creator, and that this Free-will is the only ſufficient Reaſon that can be aſſigned for it.

The Earth has another Motion, which is finiſhed by its Poles in 25,920 Years. Its Gravitation towards the Sun and the Moon is evidently the Cauſe of this Motion, as we ſhall prove in the 25th Chapter.

The Earth has yet another Revolution, much more ſtrange, the Cauſe of which is unknown, the Length of which aſtoniſhes the Imagination; and ſeems to promiſe a Duration to the human Species beyond what they dare think of. This Period conſiſts, according to all Appearances, of a million, nine hundred and forty four thouſand Years. It is here that we muſt inſert what is known of this ſurpriſing Diſcovery, before we finiſh the Article of the Earth.

A DIGRESSION.

Concerning the Period of 1,944,000 *Years, newly diſcovered.*

Egypt and Part of *Aſia*, from whence all the Sciences that now ſeem to circulate in the World devolv'd to us, preſerved antiently an immemorial, extravagant, uncertain Tradition, but which could not be without ſome Foundation. They ſaid, that prodigious Changes had been made in our Globe, and in the Heavens with regard to our Globe. The bare Inſpection of the Earth gives great Weight to this Opinion.

We ſee that the Waters have ſucceſſively covered and abandoned the Beds which contain them. The Vegetables and Fiſhes of *India*, found in the Petrifications of our *Europe*, the Numbers of Shells found in Ranges in the Mountains, render ſufficient Teſtimony to this antient Truth.

Ovid, explaining the Philoſophy of *Pythagoras*, and introducing a Diſcourſe of that Pupil of the *Aſian* Sages, ſpeaks in the Name of all the Oriental Philoſophers, when he ſays:

Nil equidem durare diu ſub imagine eâdem
Crediderim; ſic ad ferrum veniſtis ab auro
Secula, ſic toties verſa eſt fortuna locorum.
Vidi ego quod fuerat quondam ſolidiſſima tellus
Eſſe fretum: vidi factas ex æquore terras:
Et procul à pelago conchæ jacuere marinæ:
Et vetus inventa eſt in montibus anchora ſummis.
Quodque fuit campus, vallem decurſus aquarum
Fecit; & eluvie mons eſt deductus in æquor,
Eque paludoſa ſiccis humus aret arenis.

Which Verſes are thus tranſlated by Mr. *Dryden:*

That Forms are chang'd I grant; that nothing can
Continue in the Figure it began:
The golden Age to Silver was debas'd;
To Copper that; our Metal came the laſt.
The Face of Places, and their Forms, decay;
And what was ſolid Earth, converts to Sea:
Seas in their turn retreating from the Shore,
Make ſolid Land, what Ocean was before:

And far from Strands are Shells of Fiſhes
found;
And ruſty Anchors fix'd on Mountain
Ground:
And what were Fields before, now waſh'd
and worn,
By falling Floods from high, to Vallies turn,
And crumbling ſtill deſcend to level Lands;
And Lakes, and trembling Bogs, are barren
Sands:
And the parch'd Deſart floats in Streams
unknown;
Wond'ring to drink of Waters not her own.

This was the Opinion of the Eaſt; and we do it no Injury by reporting it in Verſe, the antient Language of Philoſophy.

To theſe Teſtimonies which Nature gives, of ſo many Revolutions which have changed the Face of the Earth, correſponds an Idea of the antient *Egyptians*, a People formerly ſkill'd in Geometry and Aſtronomy, before Superſtition and Sloth had reduced them to Contempt. This Idea was, that the Sun, in former Ages, roſe in the Weſt. It was a Tradition, indeed, as obſcure as their Hieroglyphicks. *Herodotus*, who may be looked upon as an Author too modern, and conſequently of little Weight with regard to ſuch Antiquities, reports in his Book *Euterpe*, that, according to the *Egyptian* Prieſts, the Sun, in the Space of eleven thouſand three hundred and forty Years (and the *Egyptian* Year conſiſted of 365 Days) had riſen twice where he now ſets, and ſet where he riſes, without there being the leaſt Change in *Egypt*, occaſioned by this Variation of the Solar Courſe.

Either the Prieſts, who related this Event to *Herodotus*, explained themſelves imperfectly, or *Herodotus* miſunderſtood them. For it might be a probable Tradition among Philoſophers, that the Sun had changed his Courſe; but that the Cardinal Points ſhould be twice changed in eleven thouſand and odd Years, was a thing impoſſible. Theſe two Revolutions, as we are going to make it appear, could not happen in much leſs than 4 Millions of Years. The entire Revolution of the Poles of the Ecliptic, or the Equator, is finiſhed in about 1,944,000 Years; and this Revolution of the Ecliptic and the Equator alone, by the Help of the diurnal Motion of the Earth, is ſufficient to turn our Globe ſucceſſively to the Eaſt, to the South, to the Weſt, to the North. Thus it is in a Period of no leſs than 1,944,000 Years, that our Globe could twice ſee the Sun riſe in the Weſt, and not in 110 Centuries only, according to the wild Report of the *Theban* Prieſts, and of *Herodotus*, the Father of Hiſtory and Falſhood.

Beſides, it is impoſſible that this Change could happen, and *Egypt* not be affected by it: For if the Earth, in turning daily on itſelf, had ſucceſſively finiſhed its Year from Weſt to Eaſt, from North to South, from Eaſt to Weſt, and from South to North, by raiſing itſelf on its Axis; it may be clearly perceived, that the Poſition of *Egypt*, and of all the Climates of the Earth, muſt have been changed. The Rains, which have ſo long continued to fall from the Tropick of Capricorn, and which fertilize *Egypt* by ſwelling the *Nile*, would have ceaſed. The Place of *Egypt* would have been removed into a frozen Zone, and both *Egypt* and the *Nile* would have diſappeared.

Plato, *Diogenes*, *Laertius*, and *Plutarch*, ſpeak not more intelligibly of this Revolution.

tion. Speak of it however they do, and are ſo many remaining Witneſſes of a Tradition almoſt loſt.

What follows is much more ſhocking, and more circumſtantial. The Philoſophers of *Babylon,* at the Time of *Alexander*'s Entry into that City, counted four hundred and three thouſand Years from the beginning of their aſtronomical Obſervations, the *Babylonian* Year being but 360 Days: But this Epocha of 403,000 Years has been regarded as a Monument of the Vanity of a conquered Nation, which was willing, according to the Cuſtom of all Nations, and all particular Perſons, to recover by its Antiquity the Glory that it had loſt by its Weakneſs.

The Sciences, at laſt, having been brought among us, and being cultivated by Degrees, the Chevalier *de Louville*, diſtinguiſhed among the Croud of them who did Honour to the Age of *Louis* XIV. went expreſly to *Marſeilles*, to ſee if the Obliquity of the Ecliptic appear'd the ſame there as it had been obſerved and fixed by *Pitheas*, above 2000 Years ago. He found this Obliquity of the Ecliptic, that is, the Angle formed by the Axis of the Equator, and the Axis of the Ecliptic, to be 20 Minutes leſs than *Pitheas* had found it. How did this 20 Minutes Diminution of this Angle agree with the Opinion of antient *Egypt*, and with the 403,000 Years of which *Babylon* boaſted? How, with a Period of the World of near 2 Millions of Years, and even, according to *Louville*'s Obſervation, of above 2 Millions? We muſt ſee the Uſe he made of it, and how there is like to reſult from it, hereafter, an Aſtronomy altogether new.

If the Angle which the Axis of the Equator makes with the Axis of the Ecliptic be 20 Minutes leſs at this Day than it was 2000 Years ago, the Axis of the Earth, by riſing upon the Plan of the Ecliptic, comes nearer it a whole Degree in 6000 Years.

Let this Angle, P, E, for Example, be about 23½ Degrees at this Day, and let it continue to decreaſe till it becomes nothing; then let it begin again to increaſe and decreaſe, it will certainly happen, that in 23½ Times 6000 Years, that is, in 141,000 Years, our Ecliptic and our Equator will coincide in all their Points; the Sun will be in the

Equator, or at leaſt will remove little from it, during many Centuries; the Days, the Nights, the Seaſons, will be equal all over the Earth. It is found, according to the Calculation of the *French* Aſtronomer, a Calculation a little reformed ſince, that the Axis of the Ecliptic was perpendicular to that of the Equator about 399,000 of our Years ago, ſuppoſing the World to have exiſted ſo long. Take from this Number, the Time that is elapſed ſince *Alexander*'s triumphant Entry into *Babylon*, and we ſhall ſee with Aſtoniſhment that this Calculation agrees very juſtly with the 403,000 Years of 360 Days, which were computed by the *Babylonians:* We ſhall ſee that they begun this Computation preciſely at the Point where the Pole of the Earth was directed towards Aries, and when the Earth in its annual Courſe had revolved from South to North; in a Word, when the Sun roſe and ſat in the Regions of Heaven which now are the Poles.

There is ſome Appearance that the *Chaldæan* Aſtronomers had made the ſame Operation, and conſequently the ſame Deduction from it, as the *French* Philoſopher? They had meaſured the Obliquity of the Ecliptic, and found it decreaſing; and riſing in their Calculations to a Cardinal Point, counted from that Point when the Ecliptic and the Equator made an Angle of 90 Degrees; a Point, which may be conſidered as the Beginning, as the End, as the Half, or as the Quarter of this enormous Period.

By this the Enigma of the *Egyptians* was unravelled, the Computation of the *Chaldeans* juſtified, the Relation of *Herodotus* clear'd up, and the Univerſe flattered with a long Futurity, the Idea of which pleaſes the human Imagination; tho' this Compariſon makes our Life appear yet the ſhorter.

This Diſcovery of the Chevalier *de Louville* was ſtrongly oppoſed, both becauſe it was very ſtrange, and becauſe it did not yet ſeem ſufficiently confirmed. An Academician had, in a Voyage to *Egypt*, meaſured a Pyramid: He found its four Sides oppoſed to the four Cardinal Points; therefore the Meridian, ſaid the Enemies of the Chevalier, has not changed during ſo many Centuries; therefore the Obliquity of the Ecliptic, which by its Diminution muſt have changed all the Meridians,

dians, in reality has not been diminiſhed. But this Pyramid was no impregnable Barrier againſt theſe new Diſcoveries: For, how are we ſure that the Architects of the Pyramid were not ſome Minutes deceived? The moſt inſenſible Aberration, in laying a Stone, had alone been ſufficient to occaſion this Error. Or, if the Builders were right, might not the Academician himſelf neglect that little Diverſity, which might be found between the Points where the Sun ought to mark the Equinoxes and Solſtices upon this Pyramid, ſuppoſing nothing to have changed, and the Points where it now marks them in Fact? Could not he be deceived in the Fables of *Egypt*, where he operated out of pure Curioſity, when *Tycho-Brahe* himſelf was deceived 18 Minutes in the Poſition of the Meridian of *Uraniburg*, his heavenly City, for which he calculated all his Obſervations? Or was *Tycho-Brahe* in reality deceived 18 Minutes, as is pretended? May not the Truth be, after all, that this Difference found between the true Meridian of *Uraniburg*, and that of *Tycho-Brahe*, proceeds partly from the Change of Heaven itſelf, and partly from the almoſt inevitable Errors committed both by *Tycho-Brahe* and by them that corrected him?

But the Chevalier *de Louville* might alſo be deceived himſelf; he might ſee a Decreaſe of Obliquity, which has no Exiſtence. *Pitheas*, eſpecially, was probably the Source of all theſe Errors: He, like moſt of the Antients, made his Obſervations with very little Exactneſs. It was worthy of that Prudence therefore, with which we now proceed in Phyſicks, to wait for new Illuſtrations of the Matter. Therefore it was proper that the few, who were able to judge of this grand Difference, ſhould remain in Silence for the preſent.

Finally, in 1734, Mr. *Godin* (one of thoſe Philoſophers whom the Love of Truth has lately conducted to *Peru)* reſumed the Thread of theſe Diſcoveries: The Examination of a Pyramid was now no more the Matter in Queſtion, for concerning this there would be Difficulties always remaining; he was to proceed from the famous Meridian in the Church of St. *Petronius*, traced by *Dominic Caſſini* in 1655, with an Exactneſs of which we are more certain than that of the *Egyptian* Architects, The Obliquity of the Ecliptic which reſulted from *Caſſini*'s Obſervation, was 23 D. 29′. 15″. But the late Obſervations put it beyond all Doubt, that this Angle of the Ecliptic and the Equator is at preſent 23 D. 28′. 20″. at leaſt if the Refractions, which enter into the Determination of the Height of the Pole, made by the Polar Heat, and conſequently into that of the Elevation of the Equator, and the Obliquities of the Ecliptic, are not a little changed ſince *Caſſini*'s Time: A Variation which many begin to ſuſpect, from the Difference of the Elevations of the Pole, obſerved in the ſame Cities after ſome Space of Time, particularly in *London*, *Amſterdam*, and *Copenhagen*; tho' theſe Obſervations are not yet ſufficient to aſſure us entirely, that from Age to Age the Air is found ſometimes more, ſometimes leſs tranſparent. It has indeed been lately diſcovered, and infallibly demonſtrated, that the Refractions at two Places, a very little diſtant, will ſometimes differ almoſt beyond Belief; which obliges an exact Obſerver, at preſent, to determine well, before every Thing elſe, the Refractions of his Horizon, if he would have his Obſervations credited:

But it is alſo known, that, according to the Experiment of Mr. *Huygens*, if a reflecting Glaſs be left in a conſtant Situation, directed towards the Top of a high Steeple, from Noon till Evening, that Top will appear more elevated towards the Cloſe of Day than at Noon, and conſequently there is an Alteration in the Tranſparency of the Air. As all this, however, contributes nothing to a Change, ſuch as we have reaſon to ſuſpect may produce the Phænomenon of this Queſtion, we ſhould be blameable to admit ſuch a dubious Fact, of which we have not yet any convincing Proof, any Phyſical Reaſons.

With regard to the Pyramids of *Egypt*, and the Invariableneſs of Meridians, which ſeems contrary to this Mobility of the Poles of the Equator; it is proper to take Notice farther, That ſuppoſing the Figure of the Earth to be not ſpheroidical, as it really is, but exactly ſpherical, this Motion of the Plan of the Equator, and its Poles, may be conceived two ways. For, either moſt of the Places, ſituated at preſent under the Equator, will, after ſome Ages, have a Meridional or Septentrional Latitude, the Equator having quitted them to come nearer the Ecliptic; (on which Suppoſition, all the Meridians will be diſordered, and any two Cities, without having changed their Place, their Diſtance, or their firſt Situation upon Earth, will nevertheleſs have changed the Point of Compaſs, with regard to each other) or, the Equator will never abandon the Places, which have always been ſituated under it, but its Plan will turn with them round the Ecliptic, without any Change being made in the Meridians, their Invariableneſs not proving the ſame Thing againſt the Motion of the Equator as in the former Suppoſition. On the contrary, reſuming the ſpheroidical Figure of the Earth, which is the true one, its ſolid Parts manifeſtly ſuſtaining themſelves, and not having a Power to quit one another, the moſt remote from the Center will remain always at the ſame Diſtance, and conſequently the Circumference of the Equator, which has once environ'd them, will never quit them; ſo that the Place of the Equator, whether moveable or immoveable, can never bring any Diſorder on the Meridians. It appears by this, that tho' the *Egyptian* Architects

chitects might have had Orders to build the Pyramids parallel to the four Cardinal Points of the World, and they may have executed theſe Orders with the utmoſt Exactneſs, this does not hinder but the Angle of Interſection of the Equator and the Ecliptic may continually vary, as much as we pleaſe.

There can be no greater Pleaſure, than to ſee the Credit of Truths, the moſt worthy of Reſpect for their Antiquity, re-eſtabliſhed, after having been conteſted in Ages ſo circumſpect, and ſo little credulous as ours. But it muſt be confeſs'd, that if the *Egyptians* and *Babylonians* were the firſt Diſcoverers of the Decreaſe of this Obliquity, they made the Diſcovery from Reaſonings much leſs certain, than thoſe from which we attribute this Diſcovery to them. *Herodotus* publiſhed his Hiſtory about a hundred Years after *Anaximander*, the *Mileſian*, firſt found out the means of meaſuring the Obliquity of the Eclyptic: And this Invention having ſoon after paſſed into *Egypt*, by the Voyages of *Cleoſtrates*, *Harpalus*, and *Eudoxus*, the *Egyptians*, who could not but find this Obliquity leſs than *Anaximander* had found it, took the Advantage from thence to do honour to their Nation; as if the Diminution, and conſequently the Meaſure, of the Obliquity of the Ecliptic, had been known among them for many thouſands of Years, at the time when this latter was but juſt diſcovered by the *Greeks*. We have already ſaid almoſt the ſame Thing of the *Babylonians*, who, equally jealous of the *Egyptians* and the *Greeks*, have advanced, by a parallel Calculation, to an Antiquity incomparably more abſurd than that of the *Egyptians*.

But, whether this Motion of the Equator does, or does not exiſt, it is demonſtrably certain, that it cannot be produced by any Mechaniſm, exactly the ſame with any diſcovered by the learned *Newton*. The Motion which moſt naturally reſembles this of the Axis of the Earth, is the variation of the Moon's Inclination; which is of no leſs than 5 Degrees, 18 or 19 Minutes, when the Nodes of the Moon are in Conjunction, or Oppoſition with the Sun; and of 5 Degrees only, when theſe ſame Nodes happen in her Quarters. It is true indeed, that, by a natural Analogy, this great Philoſopher attributes a ſmall alternative Motion to the Axis of the Earth, by which the Angle of Interſection of the Ecliptic and Equinoctial being found in the Equinoxes, for Example, to be 23 Degrees, 29 Minutes, and is ſtraiten'd in approaching the Solſtices, and enlarged again from the Solſtices to the Equator; ſo that at the Solſtices this Angle, in its ſmalleſt Dimenſion, is ſome Seconds leſs than 23 Degrees, 29 Minutes.

But theſe Alternatives of Diminution and Decreaſe produce not the circular Motion of the Plan of the Equinoctial, from one Pole of the Ecliptic to the other. This Circulation then muſt neceſſarily depend upon ſome other Cauſe, hitherto unknown, which we ſhould endeavour to diſcover, provided the Phænomenon be real.

That the Diminution of this Angle may always equal its Increaſe, the abſolute Center of Gravity of all the Maſs of the Earth, muſt be the ſame as the Geometrical Center of its ſpheroidical Figure; but this, very poſſibly, is not the Caſe. For if the Earth be ever ſo little leſs material on the Northern, than on the Southern ſide of the Equator, and if there arrive in the Body of this Planet, or on its Surface, any Change, which diminiſhes the Quantity of Matter in one Place, and augments it in another; it is evident, that the exterior Surface of the Earth, and the common Center of Gravity of its whole Maſs, muſt change Poſition with regard to each other; and as the Geometrical Center of its ſpheroidical exterior Surface remains always the ſame, it is neceſſary that this Center alſo muſt change its Poſition, with regard to that of Gravity, whenever any Reaſon, manifeſt or not manifeſt, takes away ever ſo little Matter from one Place, and carries it to another. Now the two Centers, the Geometrical Center of its Oval Figure, and that of its general Gravity, ſhould neceſſarily be in the ſame Axis of its Rotation, if this Rotation muſt be equal and uniform during 24 Hours, without being accelerated and retarded by Turns; which would be contrary to Experience.

To effectuate this Motion of the Plan of the Equator, it is ſufficient then, that there ſhould be, within the Earth, Matter which, by circulating continually, but ſlowly, may continually remove the common Center of Gravity, with regard to the Surface of the Earth, becauſe the Axis of Rotation will always follow the ſame Road as this Center.

If this Matter be not ſuppoſod to circulate, but to have a very ſmall irregular Motion, the Plan of the Equator will alſo change its Poſition with the Ecliptic, but without any certain Rule, and may be ſometimes nearer, ſometimes farther from the Center; which, perhaps, may be more probable than a perfect Circulation. But none of all this Reaſoning can have Place, till it ſhall be proved in a manner altogether inconteſtible, that the Approximation of the Equator and the Ecliptic, which the moſt ſkilful Obſervers pretend now to perceive, is real; and that there is no Illuſion, either from the Refractions of Light, or from the Inſtruments, in an Affair which is yet ſo delicate, and ſo little ſenſible in Modern Obſervations, as to relate only to a few Seconds of Diminution; ſo that it will not be till after many Ages of continued Obſervations, that any one will be able to ſay, with full Certainty, whether the Obliquity is variable, or how it is ſo.

The moſt ſhort and certain Method of terminating this Queſtion, would be to meaſure exactly the Elevation of the Pole from the Ruins of the antient City of *Syene* in *Egypt*. It is known, from the Report of *Strabo* in the laſt Book of his Geography, that this City was ſituated preciſely under the Tropic of Cancer, and that there was here a very deep Well, in which the Reflection of the Sun could never be ſeen, but juſt at Noon in the Summer Solſtice, the Sun ſhining vertically over the horizontal Surface of the Water, at the Bottom of the Well. *Strabo* adds in the ſame Place, that in travelling from *Greece*, this City was the firſt to be met with, where the Gnomons, or Columns erected vertically, had no Shadow at Noon-day once in a Year: So that here are two different Proofs, which aſſure us that in the Time of *Strabo*, or ſome Time before him, the Tropic of Cancer paſſed over the vertical Point of this City.

Now if in meaſuring at preſent the Latitude of the Place where *Syene* formerly ſtood, the Arctic Pole ſhall be found to be there elevated to 23 Degrees, 49 Minutes or more, this will be an indubitable Proof that the Chevalier de *Louville* has diſcovered the Truth, and that the Obliquity of the Ecliptic has diminiſhed 20 Minutes in the Space of 18 Centuries. I ſay, 23 Degrees, 49 Minutes or more; for the Tower of *Syene* being renown'd before *Strabo*, on Account of this Property of which we are ſpeaking, even as far back as the Time of the Prophet *Ezekiel*, who mentions it in the xxxixth Chapter of his Prophecy; it is apparent, that if the Obliquity of the Ecliptic was variable, it muſt have diminiſhed five or ſix Minutes, in the ſame Proportion, from the Time of this Prophet to that of *Strabo*, during more than five Centuries; without reckoning what Diminution it might have undergone from the Foundation of this Tower to the Time of *Ezekiel.*

But if, on the contrary, the Pole is there found to be elevated but 23 $\frac{1}{2}$ Degrees or thereabouts, we muſt conclude, without Heſitation, that, during all this Series of Ages, the Obliquity in queſtion has been conſtantly the ſame, or that its Diminution has not been any Thing conſiderable; and that the Space comprized between the Equinoctial and the Ecliptic has been very little, if at all leſſen'd. All the Difficulty would conſiſt, in diſcovering exactly the Situation of this antient City, in the neighbourhood of *Nile*, and the Iſland *Elephantine*. This Work would be a means to prevent the Cares of Poſterity, and of which to make a Merit with regard to our Children, for preſenting them with finiſhed Demonſtrations of a Truth, the clearing up of which may coſt them many Centuries.

The Enumeration which we have undertaken to make here, of the principal Particulars which regard the Earth, with reſpect to the Rank that it holds among the Planets, engages us to examine the Proofs of its ſpheroidical Figure, which we have ſuppoſed true, and to ſhew the Impoſſibility of any Alteration of Meridians. We have already given a general Idea of it in Chap. XVIII. when, in proportion to the Extent and the divers Degrees of Gravity, we made mention of the Inundation of Waters towards the Regions of the Equator, which muſt neceſſarily reſult from the Rotation of the Earth round its Axis, if it was exactly ſpherical. But as that was not the Place to prove that this Difference is ſo perceptible as to be meaſured, we proceed here to ſhew what is known of the Matter.

The Proofs, which we ſhall make uſe of, are drawn partly from phyſical Arguments, and partly from Experience itſelf. The phyſical Arguments, which prove to us the neceſſity of this Figure, ſuppoſe only, by way of Principle, the diurnal Motion of the Earth, of 23 Hours, 56 Minutes. If the Earth is exactly ſpherical, the Velocity of the Rotation of all weighty Bodies under the Equator will diminiſh their Gravity, or the Velocity of their Deſcent, in proportion as it will differ leſs from that which is neceſſary to make all weighty Bodies circulate under the Equator, without power ever to fall, or approach to the Center of the Earth; or, to cauſe that all Bodies which are under the Equator, ſhould be ſo many Satellites, which ſhould turn by their daily Motion in the Circumference of the Equator, as the Moon revolves in her Orbit. Now let us ſay, by the Rule of Three; as the Cube of the Moon's Diſtance, *viz.* 60 Semidiameters of the Earth, is to the Cube of one only of theſe Semidiameters; ſo is the Square of 39,343 Minutes, which make a Lunar Month, to the Square of the Minutes of the Revolution of the Satellites, or weighty Bodies, in the Circumference of the Earth's Equator, ſuppoſing the centrifugal Force exactly to counterbalance the Gravity. The Product of this Calculation is, $84\frac{2}{5}$ Minutes of Revolution: So that if the Day of the Satellites conſiſted of $84\frac{2}{5}$ Minutes, inſtead of 23 Hours 56 Minutes, which is 17 Times as much, there would be neither Deſcent nor Weight under the Equator.

The ſame Number of $84\frac{2}{5}$ is found without making uſe of the Moon, if we follow the Theorem of Mr. *Huygens*, by which he has found, that a Body, to turn circularly, with a centrifugal Force equal to its proper Gravity, muſt ſurround the whole Circle in the ſame Time as a Pendulum, containing a Semidiameter of the ſame Circle in Length, would employ in making two Vibrations. Now to apply this Theorem to the Circle of the Equator, and the Semidiameter of the Earth, we need only ſay, As three Feet, and

$\frac{17}{288}$ of a Foot, the Length of a Second-Pendulum, are to the Square of a Second, ſo 19,615,800 Feet, the Semi-diameter of the Earth, according to Mr. *Picart*'s Meaſure, are to 6,412,430, which is the Square of 2,532 Seconds, or of 42 Minutes, 12 Seconds. A Pendulum of the Length of the Earth's Semidiameter, therefore, would make every Vibration in 42 Min. 12 Seconds; and conſequently, to equal the Gravity to the centrifugal Force of the diurnal Rotation under the Equator, this Rotation muſt neceſſarily be finiſhed in 84 Min. 24 Seconds.

But, as it is found 17 Times more ſlow, it is evident, that ſuppoſing the Surface of the Earth exactly ſpherical, Gravity under the Equator exceeds its Diminution, or the centrifugal Force, 17 Times 17 Times, that is, 289 Times; which muſt occaſion the Velocity of Bodies Deſcent under the Equator, to be to that of their Deſcent under the Poles, as 288 are to 289; and a Second-Pendulum, which under the Pole would make 86,400 Vibrations in a ſolar Day, would make under the Equator but about 86,250: In the ſame manner as a Second-Pendulum of *Paris*, being tranſported under the Equator, and there making its curvilinear Deſcents, or Vibrations, a little more ſlowly than at *Paris*, would be retarded 2 Minutes, 5 Seconds, or thereabouts, in a Day.

Mr. *Richer*'s Experiment, made in the Iſland of *Cayenna*, Dr. *Halley*'s in the Iſle of St. *Helena*, and thoſe of the Perſons mentioned Page 196, having verified, except in a few Circumſtances, this Diminution of Gravity under the Equator, which is a neceſſary and indubitable Conſequence of the Earth's diurnal Motion; it remains, that we ſhould ſurvey the Diſorder which the centrifugal Forces of this ſame Motion would cauſe under the Circles parallel to the Equator, if the Earth was exactly ſpherical.

Every one knows, that an exact Beam, being ſuſpended in the Middle, and left in Repoſe, the Scales, or Weights, equally ſuſpended by Cords at its two Extremities, make theſe Cords, or rather the Middle of them, take Situations perpendicular to their Horizons, and which tend directly to the Center of the Earth. But if we give to this Balance a circular Motion, the Center of which is the Point of the Beam's Suſpenſion, we ſhall ſee immediately that the Scales, or Weights, will fly out of the perpendicular Lines, in proportion to the Velocity of the circular Motion; ſo that the Cords no longer follow the uſual Direction of Gravity, towards the Center of the Earth.

Let us conceive now a great curvilineal Balance, whoſe Middle is ſuſpended to one of the Poles of the Earth, and whoſe Extremities extend to an equal Elevation from the ſame Pole, on both Sides; it is evident, that if the ſpherical Figure of the Earth, which we now examine, turns round on its Axis, and carries at the ſame Time this curvilineal Balance, in a circular Motion round the ſame Axis, the Weights, which being in Repoſe would incline towards the Center of the Earth, are removed from this Inclination, and out of perpendicular Lines, on both Sides. Thus the Sine of the ſmall Angle of Deviation, comprized between the Perpendicular, and the new Direction of the Weights, will be near $\frac{1}{289}$ of the Product of the Sine, and of the Co-ſine of the Elevation of the Pole, divided by the Radius.

It is manifeſt, that, without imagining this Balance curvilineal, this Reaſoning may be equally apply'd to all Plummets, which are uſed on the Surface of the Earth. It is in this manner that we find at *Paris*, and in a hundred other Places of the ſame Latitude, that a Pendulum in Repoſe would not tend perpendicularly to the Horizon, but would make with the Perpendicular an Angle of near 6 Minutes, which would be perceptible enough, if the Earth were exactly ſpherical: But as no Deviation is found in any Part of the World, it is ſufficient Proof that the Face of the Earth is ſuch as it ought to be, in order that the Direction of Gravity might be perpendicular, which can be only in a Spheroid *.

This ſpheroidical Figure produces yet another Change, with regard to Gravity, but of ſmall Conſequence It is well known, that, without conſidering the Diminution of Gravity, of which we have been ſpeaking, Gravity itſelf varies according to the Diverſity of Diſtances from the Center of the Earth, even ſuppoſing there were no Rotation.

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* The Scales would fly out at the Æquator, whatever Figure the Beam is of, and ſo would not be perpendicular there.

tion. This is the Reaſon why the Experiments of Pendulums, tranſported into different Climates, anſwer not with the utmoſt Exactneſs to the Calculation which we have given above, tho' they all prove in general that Gravity differs ſenſibly, and that it is always weaker towards the Equator, than towards the Poles. It is this alſo, which divides the greateſt Geometricians in their Sentiments concerning the Proportion of the Axis of the Earth's Rotation to the Diameter of its Equator. Mr. *Huygens*, and after him *James Herman*, in his excellent Work *de Phoronomiâ*, have determined this Proportion, as of 577 to 578; but Sir *Iſaac Newton* gives it as of 229 to 230, about three Times more than the other. The Diverſity of theſe Meaſures proceeds only from this, that Mr. *Huygens* conſidered Gravity merely as a Force which impels Bodies towards one only Center; whereas Sir *Iſaac Newton* conſidered it as a Force by which all Bodies, and all the Particles of the Earth, even to the moſt minute, are drawn towards one another *.

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* Query then whether a Millſtone within a Mile of the Earth's Center would not be drawn almoſt as much up as down, and ſo have leſs Gravity the nearer the Center, contrary to its Law of Increaſe. MARS.

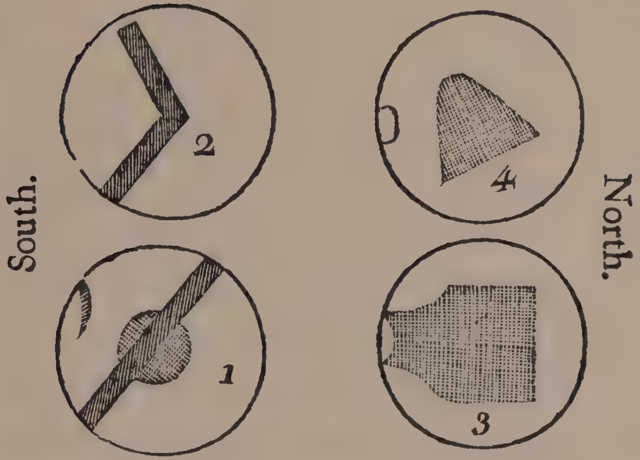
MARS.

The fourth Planet of our Syſtem is Mars. His mean Diſtance from the Sun is about 46 Million of Leagues. Of all the ſuperior Planets, it is this which has the greateſt Excentricity; nor do we know any one, among all the celeſtial Bodies, whoſe apparent Magnitude is more variable; inſomuch that his largeſt Phaſis exceeds his ſmalleſt, no leſs than 7 Times. In the Month of *Auguſt* 1719, Mars being oppoſed to the Sun, at only 2 or 3 Degrees Diſtance from his Perihelion, we yet remember that many Perſons, who had no Tincture of Aſtronomy, were aſtoniſhed to ſee this Planet, and took it for a Comet, or a new Star, juſt produced in the Heavens; in like manner as Venus was miſtaken laſt Year, when in the Month of *May*, having attained her higheſt Meridian Elevation at the Beginning of Cancer, and yet being far enough from the Sun not to be eclipſed by his Light, ſhe lanced her Rays along the ſhorteſt Road of the Northern Part of the Atmoſphere.

As the great Excentricity of Mars renders his Motion apparently very unequal, it was of him principally that *Kepler* made uſe, to examine and verify the Diſcovery he had made, of the Equality of Areas deſcribed by every Planet in particular, in equal Times: And it was alſo by Mars that he found out and proved the Neceſſity there was to admit but very ſmall Excentricities throughout the Heavens, not above half as large as thoſe that had been eſtabliſhed by the Antients.

Mars likewiſe, of all the Planets, is he which has the largeſt Atmoſphere, in proportion to his Body, at leaſt according to what we know hitherto; which is proved by the Alteration of the Colour of a fixed Star obſerved by Mr. *Romer*, as it approached and quitted the Diſk of Mars: It grew ſenſibly pale on approaching this Diſk, being yet above two thirds of its Diameter diſtant; and coming from behind the Planet's dark Body, did not recover the natural and uſual Vivacity of its Light, till it came to the Diſtance of two thirds of the ſame Diameter.

Without the Planet Mars, we ſhould be altogether ignorant of the Diſtance and true Magnitude of the heavenly Bodies: And it was the celebrated Mr. *Caſſini* the Father, who firſt thought of making uſe of the apparent Diſtance of this Planet from the neareſt fixed Stars, when he is in Oppoſition to the Sun, in order to find the true Dimenſions of our Syſtem. His horizontal Parallax, which in this Situation is large enough to be obſerved and calculated, without Danger of any remarkable Error, that is, between 26 and 27 Seconds in his Perihelion, furniſhes us with a Method of calculating the horizontal Parallax of the Sun, and of the other Planets, which cannot be obſerved by themſelves, on account of their Smallneſs. By the Spots in Mars, which we repreſent here as they appeared in 1719, it has been diſcovered, and we are convinced of it, that ſhe turns round upon an Axis always parallel to itſelf, (like that of the Earth) in 24 Hours 40 Minutes.



Or, that 36 Revolutions of Mars on his Axis, equal 37 diurnal Revolutions of the Earth.

Remarks on the Spots of Mars.

The Spots of this Planet ſeem to be more variable than thoſe of all the others. The obſcure Bands, which were obſerved in 1704, 1717, 1719, do not agree among themſelves, neither with regard to their Situation, nor to their Figure. In 1704 and 1717, an obſcure Band was ſeen, occupying more than a Hemiſphere of Mars, with this Difference, that in 1704 it had a Point in the Middle, which was not found in 1717; and that in 1717 it was farther from the Equator of Mars, and nearer his Meridian Pole, than in 1704. In 1719, a crooked Band was ſeen, formed only after the Month of *July*, the moſt Southerly Part of which, with regard to our Eyes, extended obliquely over half of the Hemiſphere of Mars, and equalled about a Quarter of a Circle, beginning between the Meridional Pole and the Equator of the Planet, and ending between his Equator and Septentrional Pole, where the two Parts of this Band, joining together, made an Angle, as repreſented in Figure 2. Before the 13th of *July*, only an obſcure rectilineal Band was obſerved, ſuch as may be ſeen in Figure 1.

Beſides theſe obſcure Bands, certain confuſed Spots, of an irregular Figure, as in Fig. 3 and 4, were diſcovered. Theſe were alſo but temporary, and had hardly any thing in common with thoſe that were obſerved before, except their Inconſtancy.

But the moſt conſiderable Spots of this Planet, are thoſe which are obſerved near his two Poles, of which however only one is ſeen at a Time, and which are commonly more clear than the reſt of the Body. Theſe Spots have been known near theſe 70 Years, and almoſt always either one or the other of them may be ſeen; which proves that they are permanent, and that the Viciſſitudes of Apparition and Occultation that they undergo, proceed only from ſome Change in the Atmoſphere of Mars, like to that of ours, cauſed partly by the different Conſtitution of the Air in Summer and Winter, and partly by the different Quantity of Rain and fine Weather, in different Parts of the ſame Climate. It was thus that from the 17th of *May* to the Month of *November* 1719, the Pole, which with regard to us is the meridional, being illuminated by the Sun, and conſequently Summer reigning there, and the Atmoſphere there being rarified as much as it could poſſibly be, the ſparkling Light of that pure Zone could ſtrike our Eyes, while that of the oppoſite Pole, which appeared to the Obſervators in 1704 and 1717, with a Luſtre equal to that of the other, was hid from our Sight by the Clouds, and congealed Vapours, which there changed the Atmoſphere, and rendered it leſs tranſparent. The Difference of the Splendour of this Zone, one half of which conſtantly preſerved the ſame Degree of Light, and the other on the contrary diminiſhed,

miniſhed, diſappear'd, appear'd again, ſeems no ill Reſemblance of the diverſity of Weather on the Andes of *Peru*, where it never rains, and in the Iſland of *Borneo*, where it rains almoſt every Day. This Effect may poſſibly be produced by other Cauſes; but it is always certain in general, that ſuch a diverſity of Appearances proceeds from the different Conſtitution of the Atmoſphere.

JUPITER.

Jupiter, the largeſt of all the Planets of our Syſtem, deſcribes in 4,331 Days, or (to count by a round Number) in 12 Years, an Orbit, the Semidiameter of which, in its mean Quantity, or mean Diſtance from the Sun, is 156 Millions of Leagues. His Diameter is ten times larger than that of the Earth. The Weight of Bodies, which tend towards the Center of this Planet, or the Way that they make in falling directly upon his Surface, may be calculated.

Manner of calculating the Weight of Bodies, which deſcend upon the Surface of Jupiter.

For this Purpoſe, we are to ſearch firſt the Periodical Time of a Satellite, that ſhould glance along the Surface of Jupiter, which is found by this Rule: As the Cube of 25 $\frac{1}{3}$

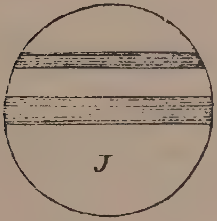
Semidiameters of Jupiter, (the Diſtance of his 4th Satellite) is to the Square of its Periodical Time, which is 16 $\frac{2}{3}$ Days; ſo the Cube of a ſingle Semidiameter of Jupiter, is to the Square of the Periodical Time ſought for. By this it is found, that ſuch a Satellite, near the Surface of Jupiter, would finiſh its Revolution round that Planet in 193 or 194 Minutes.

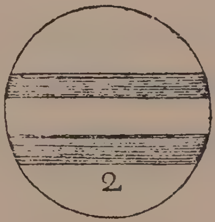
As all ſorts of Gravities are in direct Proportion of the Radii of the Circles, which the ponderous Bodies deſcribe, without falling, and in reciprocal Proportion of the Squares of the Periodical Revolutions, the Quantity of the Gravity of theſe Bodies upon Jupiter is determined in this manner: As 1 Semidiameter of the Earth is to 10 $\frac{1}{2}$ of the ſame Semidiameters, which are the meaſure of that of Jupiter; ſo 15 $\frac{1}{2}$ Feet of Deſcent upon the Earth, during the firſt Second, are to 158 $\frac{3}{8}$ Feet of Deſcent on Jupiter during the firſt Second; if the Periodical Times of the Satellites, at the Surfaces of Jupiter and the Earth were equal. But having found above, that the Periodical Time of a Satellite of the Earth, near its Surface, is 84 $\frac{2}{5}$ Minutes,

nutes, we muſt proceed thence to this laſt Rule: As the Square of 193 ½ Minutes, is to the Square of 84 ⅖ Minutes; ſo 158 ⅜ Feet of Deſcent, (if the two Periods are equal) are to 30 Feet of the true Deſcent upon Jupiter. The ſecond Pendulum then, in Jupiter, muſt be 7 ½ Feet in Length.

The ſame Conſiderations ſhew us alſo, that Jupiter's polar Diameter, or Axis of Rotation, is ſhorter than that of his Equator, and that this Difference muſt be much more ſenſible upon the Surface of Jupiter, than upon that of the Earth. The diurnal Revolution of Jupiter is 9 Hours and 56 Minutes; and the Revolution of the loweſt Satellite, which could poſſibly glide round him, having been found to be 194 Minutes, which is in a manner but the third of his diurnal Revolution; its remaining Gravity, that is, as diminiſhed by the Centrifugal Forces under the Equinoctial of Jupiter, will be to its primitive Forces ſuppoſing the Figure of Jupiter exactly ſpherical) as 8 are to 9. This then ſhews the Proportion of his ſhorteſt Axis to his longeſt, to be, within a Trifle, as 17 are to 18, if we calculate according to the Principles of Mr. *Huygens* and *Herman*, and as 7 are to 8, if we follow thoſe of *Newton*, founded upon the mutual Gravitation of all the interior Parts of the Planet. The Sentiments of Sir *Iſaac* ſeem to be ſupported by the Obſervations of Mr. *Caſſini* the Father, reported at the End of the 19th Propoſition of the 3d Book of his Philoſophy, where it is ſaid, that the Diameter of Jupiter from Eaſt to Weſt, is viſibly greater than from South to North.

The obſcure Bands of Jupiter, extended along his Diſk, and always parallel, in a manner, to his Equator, are repreſented in the two following Figures.





This Equator makes with the Orbit of Jupiter, an Obliquity but of 2 Degrees 55 Minutes; whereas ours is of 23 ½ Degrees. Theſe Bands ſeem to be nothing but Exhalations, which in riſing, and joining together, take a Circular Figure. It is true, they never are viſible all entire at a Time; witneſs, in particular, that Meridional Band, which is produced, as it were, every ſix Years, and which always exhibits to us a black Spot, ſituate on its Northern Border; as it was obſerved in the Years 1665, 1677, 1713, in the Month of *December*, and in *April* of the Years 1672 and 1708. By comparing the antient Obſervations with thoſe that have been lately made, it is remarked that theſe Bands, which at firſt appeared ſubject to Alterations altogether unaccountable, and which followed no Rule, have nevertheleſs Returns very regular, which may put us in a Capacity, hereafter, to predict their Appearances with the ſame Certainty, as we now calculate the Eclipſes.

Remark on the black Spot of Jupiter.

The Band which we have been ſpeaking of, accompanied with a black Spot, appears commonly when Jupiter is in the laſt Degrees of Virgo and Piſces, near the Time of his Oppoſition with the Sun. What is moſt particular in it is, that theſe Appearances follow the true, rather than the mean Motion of Jupiter: For we are very ſure, that from the

Oppoſition of this Planet with the Sun in Piſces, to that which happens in Virgo, there are ſix Years and a half, and five and a half only from this to the Return of the former, the whole together making 12 Years, the Time of Jupiter's periodical Revolution. This ſhews us, that if we could remark all the Mutations that happen to theſe Bands, and which, without doubt, are effected at certain Signs of the Zodiack, as well as the Phænomenon of the black Spot, there would be room to hope, that the Order of their Return might be predicted, as well as that of the black Spot.

It is principally to this ſame Spot, that we owe the Knowledge we have of the diurnal Revolution of Jupiter; the Velocity of which, in proportion to the Magnitude of his Body, would, doubtleſs, ſurprize us, if Mr. *de Mairan* had not demonſtrated the Poſſibility of it, in a learned Memoir, inſerted among thoſe of the Academy in the Year 1729, where he ſhews, that the Difference there is between the Weight of the inferior Part of a Planet, which is turned towards the Sun, and that of the ſuperior Part, which is turned from it, is capable of producing ſuch a Rotation from Weſt to Eaſt.

This Spot is as well known to Aſtronomers, as the Situation of a celebrated City is to Geographers; and its Meridional Latitude upon the Surface of Jupiter, is determined at about 16 Degrees, as that of any remarkable Place may be upon Earth. It is true, that in obſerving the Revolutions of Jupiter, at the middle of his Parallel expoſed towards us, they have not always been found quite the ſame, by the Difference of a few Seconds; though it be very natural to ſuppoſe them always equal to one another, as are thoſe of the Earth: But this is of no great Conſequence; and in an Enquiry of ſuch a Nature, far from blaming the Aſtronomers, we ought to admire their Sagacity, and be very well pleaſed that they differ only in a few Seconds.

Why the Satellites of Jupiter appear ſometimes leſs than ordinary.

The Satellites of Jupiter, and chiefly the fourth being turned towards us, exhibit obſcure Spots, which makes them ſometimes appear much leſs than they uſually ſeem: They even occaſion the fourth, between whiles, to diſappear entirely, when it is far diſtant from the Body and Shadow of Jupiter. But Aſtronomers have not yet determined, whether theſe Spots are produced ſuddenly, or whether it be the Rotation of the Satellites on their Axis, that diſcover them to us at one Time, and hides them at another: Though there ſeems to be much odds on the ſide of the Rotation, becauſe of the periodical Circumſtances that are ſaid to have been obſerved in the fourth Satellite. Or, perhaps, the Shadows of the Satellites themſelves occaſion mutually ſmall Eclipſes among them, which we can perceive only by a Diminution of their Luſtre: But this is a Point that has not yet been examined.

SATURN.

Saturn finiſhes his Courſe round the Sun in 29 Years and an half. If, counting roundly, the mean Diſtance of the Earth from the Sun is, as we have every where ſaid, 30 Millions of Leagues, it follows, by parity of Reaſon, that the mean Diſtance of Saturn from that Luminary is between 285 and 286 Millions of the ſame Leagues. This is the laſt Planet, and the moſt diſtant from the

Sun, of any we know: At leaſt, there has not yet been diſcovered any Body beyond it in the Heavens, that has a conſtant Orbit, and turns circularly. The Comets, it is true, journey through Regions much more remote than Saturn: But as their Excentricity is much greater than that of the ordinary Planets, they make no Part of the Planetary Syſtem which we conſider in this Chapter. For even if we were to ſuppoſe that any one of them regularly revolved round the Sun, for Example, at 600 Millions of Leagues diſtance from the univerſal Center of our Syſtem, of what uſe would the Light and Heat of that Luminary be to it, at a diſtance where he could not appear larger than Jupiter and Venus appear to us? I have ſuppoſed 600 Millions of Leagues for the mean Diſtance of this pretended Body from the Sun, becauſe if this Diſtance were leſs, the Planets would embarraſs and attract one another too much by their reciprocal Gravitations.

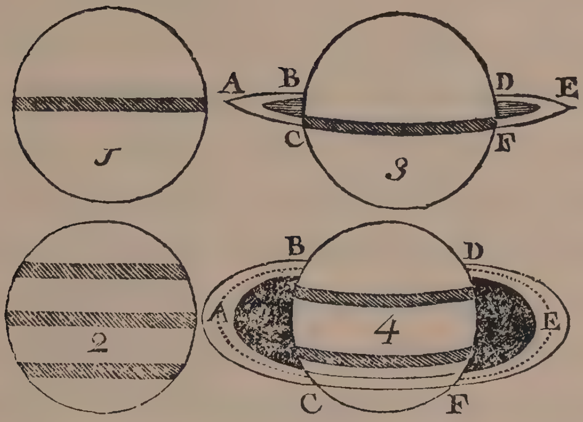
Calculation of the Weight of Bodies, which fall upon the Surface of Saturn.

The Diameter of Saturn is near 10 Times larger than that of the Earth. By means of this we may calculate the Proportion of Gravity upon Saturn, with that which we experience upon our Earth. His laſt Satellite being diſtant from him between 53 or 54 of his Semidiameters, that is, the Radius of its Orbit being between 53 and 54 Times greater than the Semidiameter of Saturn, its Revolution ought to be made in 79 Days, 22 Hours, or 1918 Hours. I ſay then; as 157,464, the Cube of 54 Semidiameters of Saturn, are to one, or to the Cube of a ſingle Semidiameter of the ſame Planet; ſo 3,678,742, the Square of 1918 Hours, are to about 23 $\frac{2}{5}$; the Square Root of which being extracted, the periodical Time of this Revolution is found to be 4 Hours, and $\frac{5}{6}$, or 4 Hours, 50 Minutes. Therefore a Body, which ſurrounded the Surface of Saturn, without being entirely drawn to it, would require 4 Hours, 50 Minutes for that purpoſe, as we have juſt now ſeen.

To find, in the next Place, how many Feet the ponderous Bodies on the Surface of Saturn deſcend in the firſt Second of Time, I proceed thus. As 1 Semidiameter of the Earth, divided by the Square of 84 Minutes, and $\frac{2}{5}$, the Number found Page 282 is to 9 $\frac{1}{2}$ Semidiameters of the Earth, or to one Semidiameter

diameter of Saturn, divided by the Square of 290 Minutes, which we have juſt found; ſo 15 Feet, the Deſcent of one Second upon the Earth, are to 12 Feet of Deſcent upon Saturn during the firſt, and ſomewhat more. But this Gravity of Bodies towards the Center of Saturn, ſuffers a conſiderable Diminution, by their Gravitation in a contrary way, towards the Cavity of Saturn's Ring, as we ſhall prove in the Sequel.

The following Figures repreſent to us the different Configurations of Saturn: 1. His round Phaſis, with a ſingle obſcure Band in the middle, cauſed by the Shadow of the Ring, and its obſcure Part, that receives no Rays from the Sun. 2. The ſame round Phaſis, with other Bands, in the manner they were ſeen in 1715. 3. The Phaſis of his Ring, which diſappears, and appears again after having been ſome Time inviſible. 4. That Ring in its greateſt Magnitude, with Bands that environ the Diſk of Saturn, as they were ſeen in 1696.



The exterior Diameter of Saturn's Ring, from one Extremity to the other, is to the Diameter of that Planet as 9 to 4, according to the Meaſure of Mr. *Huygens*, or as 11 to 5, according to that of Mr. *Caſſini*. The interior Diameter, comprized between the two oppoſite Cavities, is to that of Saturn as 6 $\frac{1}{2}$ to 4: For from the Body of Saturn to the Cavity of his Ring, there is juſt as much Space as from that Cavity to the outward Circumference. If Saturn himſelf be 30,000 Leagues in Diameter, then from his Surface to the Cavity in Queſtion will be 9,375 Leagues, and from thence to the Extremity 9,375 Leagues alſo, inſtead of 8000, the uſual Computation.

The fourth Figure repreſents to us the greateſt opening of this Ring, when its Breadth, from B to C, or from D to F, appears equal to half its Length from A to E. From this Proportion of Length and Breadth is calculated the Angle that this Ring makes with the Orbit of its Planet, which is from 30 to 31 Degrees. It is remarkable, that in the midſt of its apparent Breadth is obſerved an obſcure Line, ſuch as is marked out by the Points in the Figure. The Colour of its interior Part, which is neareſt the Body of the Planet, appears more lively and luminous than that of its exterior Part, which is fartheſt from the Body of the Planet, and the black Line, we juſt now mentioned, makes the Separation of theſe Parts. Thus every Time that this Ring diſappears, its exterior Part diſappears firſt; for the other continues viſible ſome Days after.

In the Years 1714 and 1715, when this Ring was twice ſeen to diſappear and appear, it was obſerved, that its Oriental Part withdrew from Sight a Day or two ſooner than the Occidental, and, on the contrary, that this ſame Occidental Side diſcovered itſelf a Day or two ſooner than the Oriental. Mr. *Caſſini*, the Father, had before obſerved ſomewhat like it in 1671; which made him judge, with Reaſon, that the Parts of this Ring which are of the ſame ſide, for Inſtance A, B, and D, E, of the 3d Figure, are not in the ſame Plane, and conſequently that this Ring is thinner, and more ſharp at its Extremities A and E, than towards theinward Cavity B, C, or D, F.

Reaſons of the diſappearing of Saturn's Ring.

There are two different Cauſes, which occaſion our loſing Sight of this Ring. The firſt is, that its Plan returning from being oppoſed to the Sun, its two Sides receive the Rays of Light but very obliquely; which occaſions that Light to become too feeble to ſtrike our Eyes. This happens when Saturn, with regard to the Sun, is in 19 Deg. 45 Min. either of Piſces or Virgo. If there were no other Cauſe that produced the round Phaſis of Saturn but this, it would never continue above a Month; as was proved by Obſervations made in the Years 1685 and 1701. Towards the End of the Appearance, the Shadow of the Ring upon the Body of Saturn was perceived more clearly, and appeared a little above or a little below the middle of his Diſk, as repreſented in Fig. 1.

The ſecond Cauſe which renders the Ring inviſible, is the Coincidence of its illuminated Part with the viſual Ray, which paſſes on the Side which is not illuminated *. The Terms of this Appearance are leſs limited than thoſe of the other before ſpoken of: However, one is always ſure of ſeeing it twice, when Saturn, oppoſed to the Sun in 19 Deg. 45 Min. of Piſces or Virgo, is retrograde with regard to us. His Latitude, being obſerved from the Earth, can differ one Time from another but very little; but this little is nevertheleſs ſufficiently perceptible, to advance or prorogue theſe Terms. In 1671, there were more than ſix Months between the two Diſparitions of the Anſæ, computing from the End of *May* to the 8th of *December*. The Place of Saturn, with regard to the Sun, was the firſt Time in 13 Degrees of Piſces, and the 2d Time in the Beginning of the 20th Degree. In 1714, Oct. 12, the Day on which the Anſæ diſappeared, Saturn with regard to the Sun was in the beginning of the 17th Degree of Virgo; and the 22d of *May* 1715, the Day of the ſecond Diſparition, he was advanced to 21 Degrees and an half of the ſame Sign; but the Time which elapſed between theſe two Diſparitions, was not more than 5 Months and ſome Days. Thus the round Phaſes towards the beginning of *July* 1744, and in the Month of *May* 1760, were not redoubled at all; and we ought, conſequently, to leave to Poſterity the Obſervation of the Return of this Phænomenon.

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* The two Cauſes are, the Plane of the Ring paſſes either through the Sun, or though the Earth, in both which Caſes it becomes ſcarce viſible.

Many People are curious to know if this Ring be a continuous or ſolid Body, or if it be not compoſed of Satellites, which are ſo near the one to the other, that our Sight cannot diſtinguiſh them. The laſt of theſe two Conjectures ſeems to me very probable. For if it be objected, that the Motion of all theſe Satellites, in one common Orbit, cannot ſubſiſt without their interrupting each other, let them be ever ſo little excentrical; it will be ſufficient to anſwer, that this Motion is not excentrical at all. If it be ſaid farther, that the ſuperior Satellites cannot finiſh their Periods in the ſame Time as the inferior ones, becauſe the Gravity, or centripetal Force of their circular Motion, diminiſhes in reciprocal Ratio of their Diſtance from the Center of Saturn; I anſwer again, that this Difference of their Periods is in reality what is pretended, but that the exact reſemblance of all the Satellites of one and the ſame Order, makes us regard this Collection of ſeparate Satellites as one continued Body.

There remains yet one ſmall Difficulty more to be removed. That Orbit, it will be ſaid, far from being exactly circular, is elliptical, its Grand Axis being always perpendicular to a Line drawn from the Center of the Sun to that of Saturn; becauſe, as all the Satellites are but ſo many Moons, they muſt, for this Reaſon, obey the ſame Laws of Gravitation as our Moon. Now as the Orbit of the Moon is neceſſarily flatten'd a little in the Conjunctions, as well as the Oppoſitions, and is more curve in the Quadratures, as we have proved in Chap. XXII. it follows that the ſame Variation muſt needs arrive in that of the other Satellites. The Matter, therefore, depends only upon the Difference of Saturn's

Gravitation upon the Sun, and that of his Satellites upon him; and it is of this Difference that we ſhall give the Meaſure in Chap. XXV.

The Bands of Saturn, which, being parallel with his Ring, ſhew us, that what cauſes them is elevated to a great Diſtance above the Surface of that Planet, becauſe their Curvature is little or not at all ſenſible; prove indubitably, that Saturn is encompaſſed with an Atmoſphere much more extenſive than ours. But ſuppoſing, as above, that this Ring is compoſed only of an infinite Number of Satellites, it will not be neceſſary to extend it ſo far as them. And how vaſt ſoever this Atmoſphere may be, it muſt be incomparably more tranſparent than ours, ſince the Fixed Stars, which are ſometimes ſeen between the Anſæ and the Body of Saturn, ſuffer there neither Refraction nor Change of Figure, as in all other Atmoſpheres.

It is a very remarkable Thing, that among the 5 Satellites of Saturn, there are 4 which make their Revolutions in the ſame Plane with his Ring, and that only the 5th has a particular Orbit. The Inclination of the Orbit of this laſt, from that of Saturn, is but between 15 and 16 Degrees; whereas the 4 others circulate in a Plane, whoſe Inclination from that of their principal Planet is 30 Degrees, or more. The Nodes therefore, of the one and the four, are a little different. Theſe latter have the ſame Nodes as the Ring, namely, in 19 Degrees, 45 Minutes of Piſces and Virgo; but the other cuts the Orbit of Saturn rather at 15 Degrees, that is, in the 4th, or 5th Degree of the ſame Signs.

Diminution of Saturn's Motion.

Before we leave Saturn, it is neceſſary to remark one Particular more concerning his Motion, which has not yet been obſerv'd with regard to the other Planets. All the more antient Obſervations, being compared together among themſelves, as well as with thoſe of modern Date, give us an Eſtimate of his mean annual Motion at 12 Degrees, 13 Minutes, and between 33 and 36 Seconds, at moſt. But the modern Obſervations only, compared with one another, give that ſame Motion as diminiſhed ſome few Seconds, reducing it to 12 Degrees, 13 Minutes, and between 20 and 29 Seconds. Other ſmall Inequalities have been obſerved in the Motion

tion of Saturn, ſince the Time of *Tycho-Brahe*; but which all agree to ſhew us, that his mean Motion is leſs ſpeedy at preſent, than it was in the Time of the *Egyptians* and *Chaldeans*. Mr. *Caſſini* has proved this beyond Diſpute, in a Memoir preſented to the Academy, *January* 10, 1728, by comparing the modern Obſervations, as well as thoſe of *Ptolemy*, with a very antient Obſervation made the 1ſt of *March* of the Year 4485 of the Julian Period.

Though Sir *Iſaac Newton* has proved, that when Jupiter is the neareſt to Saturn that he poſſibly can be, he produces a manifeſt Change in the Motion of that Planet; yet the Diminution of Saturn's Motion is too ſenſible, and of a Nature too different from what it ought to be, for us to ſuppoſe that Jupiter is the only Cauſe of it. In fact, if there were not other Bodies that contributed thereto, how could it happen, that, in the greateſt Proximities of theſe Planets, the Motion of Saturn ſhould be ſometimes accelerated, and ſometimes retarded, as it undoubtedly is, according to the Obſervations reported by Mr. *Caſſini*?

I believe therefore, that the Diminution of Motion, which Saturn more ſenſibly experiences than all the other Planets, is cauſed by the Attraction of many Comets *, which traverſe immenſe Regions of the Univerſe, beyond the Orbit of Saturn. Their Number and Magnitude are conſiderable enough to have a ſenſible Effect, with regard to the Gravitation of Saturn upon the Sun, which is equal but to a 9th Part of the Earth's Attraction towards the Center of our Syſtem. Thus the Inequalities of this Diminution are more commodiouſly explained by the different Proximities of the Comets, than by any other Cauſe; and if the inferior Planets feel leſs than Saturn from their approaches, it is becauſe the attractive Power of the Sun has much more the Advantage over that of the Comets in theſe lower Regions, than it has in that of Saturn; as we have before ſaid.

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* This may be true; but that is no reaſon to believe it; and it may not be true, for the Comets being near to, or far from Saturn, are very accidental, and may cauſe, increaſe, as much as Diminution of Motion; for the Moon moves faſter in Conjunction when neareſt the Sun, than in her Quadratures *cæteris paribus.*

CHAP.

CHAP. XXIV.

Of the Zodiacal Light, the Comets, and the fixed Stars.

Of the Zodiacal Light.

CERTAIN Hypotheſes, by which the Phænomenon of the Zodiacal Light is explained, ſeem contrary to Sir *Iſaac Newton*'s Demonſtrations concerning the Motion of Bodies in reſiſting Mediums. This is what we muſt endeavour to clear up; and it is principally for this Reaſon, that we make any mention of the Zodiacal Light in the preſent Work.

The Zodiacal Light is a Brightneſs like that of the *milky Way*, and ſometimes more luminary: It extends almoſt the whole Length of the Zodiack, to 50, 60, 70, 80, 90, and ſometimes to 100 Degrees and more from the Place of the Sun, on one Side and the other. Its Points, and a great Part of its luminary Arch, when it is not obſcured by, or intermixed with our Twilight, ſeem to have an annual and diurnal Motion round the Earth.

Earth, ſimilar to that which is vulgarly attributed to the Sun. According to the learned Remarks of Mr. *De Mairan*, drawn from the Obſervations of Meſſ. *Caſſini*, *Eimmart*, *Kircher*, and others, 'tis at about the End of Winter, and the Beginning of the Spring, that the Evening is moſt proper in our Climates to take a good Obſervation of this Light; and the Morning towards the End of Summer, and the Beginning of Autumn. This Difference is an Effect of the different Poſition of the Ecliptic upon the Horizon, which occaſions the Point of Light in Queſtion to fall ſometimes higher, ſometimes lower.

The Angle at the Point, where the two Sides reunite, is very unequal; varying from 20 Degrees, to 8 only. Mr. *de Mairan*, moreover, reports certain Obſervations of Mr. *Caſſini*, who had found it of an irregular Figure, and curve like a Sickle; and of Mr. *Facio de Duilliers*, who deſcribes the Sides with ſuch Points as are called in Geometry Points of *Re-curvature*, or contrary Reflection, like thoſe of two Conchoids upon the ſame Aſymptote.

One of the moſt eſſential Particulars, that we know concerning this Phænomenon, and for which we are indebted to the great Sagacity of Mr. *de Mairan*, is, that the middle Section of this Light, or of the Matter that reflects it towards us, is the ſame as the Plan of the Sun's Equator, they both having the ſame Nodes with our Ecliptic, with which they make an Angle of 7 Degrees and a half. This is, at leaſt, a probable Demonſtration *, that this Matter belongs naturally to the Sun: It is not without Reaſon, therefore, that the Name of ſolar Atmoſphere has been given it. Tho' we muſt not confound it with the Atmoſphere that encompaſſes the Sun nearer his Body, and in which ſwim the ſolar Spots, making with it their periodical Revolution in 25 Days and an half.

The Figure of this outward Atmoſphere is a very flat Spheroid, whoſe greateſt Diameter is often 5, or even 8 or 9 Times larger, than that which is imagined from one Pole to the other. Its Extent at different Times is ſo unequal, that its ſuperior Point is ſometimes much below the Orbit of the Earth, and ſometimes much above it. This inclined Mr. *de Mairan* to believe, that this Spheroid was very excentrical, and that its Apſides had a Motion much more quick, and perhaps leſs regular, than thoſe of the planetary Orbits. It is evident then, that the Aphelion of this Spheroid muſt extend to between the Orbits of Mars and the Earth, and that its Perihelion muſt terminate above the Orbit of Venus, without reaching to that of the Earth.

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* Demonſtration muſt be taken here in a large Senſe Extending to a probable Conjecture.

On this Occaſion it is pertinent to enquire, How it comes to paſs that the Earth and the Moon, which both enter this ſolar Atmoſphere, feel no Reſiſtance from Matter, that muſt neceſſarily have ſome ſort of Denſity? Why the Velocity of their Motion is not retarded? Why, in a Word, the Orbit of the Earth becomes not gradually leſs, from Age to Age, as it muſt infallibly do, if this Motion was made in a Medium that reſiſts?

It is an inconteſtible Truth, and demonſtrated by Sir *Iſaac Newton* in the 4th Section of the 2d Book of his Philoſophy, that the Denſity of a Medium being laid down in reciprocal Proportion of the Diſtances from the Center of Motion, and the Gravity in double reciprocal Proportion of theſe ſame Diſtances, the circular Motion muſt change into that of ſpiral; and that this Spiral is preciſely the ſame that *Deſcartes* and Father *Merſenne* firſt diſcovered; namely, that which divides all the Radii proceeding from one only Center, under an Angle always equal. Therefore, if the ſolar Atmoſphere invelops the Earth and the Moon, the Years ought continually to grow ſhorter, becauſe the Orbit is continually contracted; the Velocity both of the annual and diurnal Motion, muſt always diminiſh; the apparent Diameter of the Sun will grow larger to our Eyes; his Heat, with regard to us, will augment, till at laſt it deſtroys every living Creature upon Earth.

I think myſelf able to ſolve this Difficulty, in the following manner. All the ſmalleſt Parts of this Atmoſphere are as ſo many little Planets, which turn round the Sun almoſt in the ſame manner, and the ſame Senſe, as the great ones which we have hitherto known under that Name. Hence it follows, that they have themſelves, continually, Velocities very little different from thoſe of the Earth at the ſame Diſtances from the Sun.

Every one ſees, that an Aſſemblage of Particles, which turn with the ſame Rapidity as a Body of conſiderable Magnitude, that is encompaſſed by them, cannot make any Reſiſtance to the Motion that this Body makes from the ſame Principles. Every one ſees alſo, that the Velocities of this Aſſemblage of minor Planets, if they ſometimes reſiſt a little the Motion of a greater that happens to be among them, theſe Velocities being increaſed on the oppoſite Side, will ſoon make it regain what it before had loſt.

We are obliged, particularly, to the celebrated *Facio de Duilliers* for this Idea. Tho' that great Geometrician did not foreſee the Inconvenience, that would ariſe from the Reſiſtance of this Matter with regard to the Motion of the Earth, the Moon, Venus, and Mercury; he was yet the firſt who let us know, that this Light was probably a ſpheriodical Collection of ſmall Planets; as the Milky Way is only an infinite Number of fixed Stars, ſo ſmall that we cannot diſtinguiſh them.

But

The firſt Objection againſt the Sentiment of Mr. de Duilliers.

But how is this? Some one will ſay, You have deſtroy'd the Vortices of *Deſcartes* in your 16th Chapter, and would you now eſtabliſh another Vortex, entirely contrary to your Principles? This Atmoſphere, which, according to you, turns inceſſantly round the Sun, and whoſe Motion extends beyond the Orbit of the Earth, is it not a new Tourbillon, which you ſubſtitute in the Place of that you have taken ſo much Pains to annihilate, in favour of *Newton*'s Philoſophy? And, *Vortex* againſt *Vortex*, why is not that of *Deſcartes* as good as yours?

To this I anſwer, That the Vortices of *Deſcartes* are very different from the circular, or elliptical Motion of the ſmall Planets of this Atmoſphere; to which I conſent that the Name of Vortex may be given, if any one approves of it, provided he allows me at the ſame time, that it has no Reſemblance with thoſe of *Deſcartes* *. It is not neceſſary to repeat here all the Inconveniences of theſe Vortices, which we have examined in the preceding Chapters; we will be content with mentioning only one Thing, in which they differ from that we are treating of. That the Vortices of *Deſcartes* may, in Fact, have Force ſufficient to carry round the Planets that ſwim in them; it is neceſſary that the Planets ſhould never have either more or leſs Matter than the Part of the Vortex that puts them in Motion; which is contrary to Experience; for their Motion in their Aphelia is much ſlower than in their Perihelia, and yet the Quantity of Matter which they contain, is always the ſame. That which gives them their Rotation, therefore, is not a Power imprinted on them by any foreign Matter; for if it were, that Matter being more large in their Aphelia, and more cloſe in their Perihelia, it would produce a quite contrary Effect*. But our Vortex muſt not be taken for a primary Spring of the planetary Motion, becauſe we conſider Gravity, or Attraction, towards the Sun, as the true and primitive Cauſe of that Motion. All the Uſe we make of it, in ſhort, is only to retard the Motion of the Earth, and the inferior Planets *; which is very different from imprinting a Motion on them, like the Vortices of *Deſcartes.*

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* Of that there muſt be ſpecial Care taken.

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* But if the Diſtance between the Sun and the Earth in the Vortex be ſometimes greater, the Earth having broader Space will move ſlower therein.

A ſecond Objection.

An Objection much more real may be made, from the Nature of circular or curvilineal Motion, cauſed by ſome central Body towards which all others are attracted. There is no Doubt but that the Center of Powers muſt be always in the ſame Plane in which the Motion is made; for this is a neceſſary Conſequence of the Demonſtrations, by which, in the 19th Chapter, we proved the Equality of Areas deſcribed in equal Times. How then, it will be ſaid, can it be poſſible that two or more Bodies, whoſe Circulation begins in different Planes, but at equal Diſtance from the Sun, ſhould avoid claſhing together ſomewhere, before they finiſh even their firſt Revolution; ſince it is impoſſible that two different circular Planes, which have the ſame Center, ſhould avoid interſecting each other in two Points of their Peripheries? We do not ſee, however, that this happens with regard to the Matter that produces the Zodiacal Light, becauſe ſuch a Claſhing as this would ſoon reduce it into one Maſs, and make of it a new Planet, according to the Theorems of Motion cauſed by Percuſſion, demonſtrated ſo clearly by Meſſ. *Mariotte*, *Huygens*, and *Herman*. Tho' certain Sparks of this Light obſerved by Meſſ. *Caſſini* and *de Quilliets*, demonſtrate pretty clearly that this Claſhing of the little Bodies that compoſe the Matter of it, is a very common Thing, this does not hinder that Matter from continuing to ſubſiſt, or from having its Viciſſitudes of Diminution and Increaſe. But a Claſhing in the Interſection of two, or more Plans, ſuch as that we have juſt been ſpeaking of, has never been remark'd, and certainly never will be.

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* But the Particles about it moving equally faſt, as Page 319, Line *ult.* they can be no Hinderance. See alſo Page 327. l. 9.

To ſolve this Difficulty, we muſt conſider what would happen if there was a ſecond Earth, of the ſame Figure and Magnitude with ours, and if theſe two Earths were ſo to touch one another at the two Poles of their common Orbit, as that the meridional Pole of the one was applied immediately to the ſeptentrional Pole of the other: It is certain that the Center of the one and the other would deſcribe a particular Orbit, whoſe Plane would not only not paſs thro' the Center of the Sun, but would even be diſtant from it the whole Semidiameter of each.

I proceed farther. If in the Room of theſe two Earths we ſuppoſe 4, 6, 8, or more, we muſt neceſſarily recur to the ſame Reaſoning; and the Multiplication of theſe Bodies on every Side, will produce only a Multiplication of particular Orbits. But the common Center of Gravity of all theſe Earths joined together, ſituated at the Point of Contact of the two middle Poles, will at the ſame Time deſcribe an Orbit that ſhall hold the middle Place of all the reſt, and paſs unavoidably thro' the Center of the Sun *.

To return to the little Bodies that compoſe this Atmoſphere; let us ſuppoſe all thoſe which are at the ſame Diſtance from the Sun to touch one another, and there is no Doubt but they will unite eternally, as would do a Row of Earths, which had all equal Revolutions round the Sun. A ſuperior or inferior Order of theſe Bodies, it is true, would make

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* Theſe are like the ingenious Hypotheſes of *Deſcartes*, that will not ſolve Difficulties except they be proved true.

a particular Revolution in a Period of Time fferent from that of the preceding; but they would be always in Union among themſelves, and without ever quitting thoſe of the ſame Rank. It ſignifies little whether the different Ranks, ſuperior and inferior, touch one another, or not, provided there be neither Inequality nor Friction, which may retard their Motion.

A third Objection.

A third Objection, that may be made againſt the Motion of the ſolar Atmoſphere, we imagine is this: The periodical Revolution of the Sun's Spots, and conſequently of the lower Part of this Atmoſphere, with which theſe Spots evidently make their Revolution, conſiſts of 25 Days and an half, which are counted from the Time that one Part of this Atmoſphere is under any particular fix'd Star, to the Return of the ſame Part under the ſame Star.

Let us now compare the periodical Revolution of the Sediment of the ſolar Atmoſphere with the Time employ'd by the Parts ſituated in an Elevation equal to that of the Earth. To effect this, we begin by laying it down as a Principle, that all Planets, both great and ſmall, make their Revolutions in the ſame Region of Heaven in equal Times*. This is what no Perſon can deny, without contradicting Experience itſelf, which proves that the Diſproportion of the Maſſes of Jupiter, Mars, and Mercury, creates no Diſproportion in the Times of their periodical Revolutions.

The planetary Bodies or Particles of this Atmoſphere, being at an equal Diſtance with the Earth, will make their Revolutions then in a Year; but to explain the Thing fully, we muſt have Recourſe to this Rule of *Kepler:* As the Cube of 213 Semidiameters of the Sun, which make the mean Diſtance of the Earth from that Luminary, is to the Square of 525,949 Minutes, or a Year; ſo is the Cube of one ſingle Semidiameter of the Sun, to the Square of between 169 and 170 Minutes. The Bottom, or Sediment, of the ſolar Atmoſphere, ought then to turn in between 169 and 170 Minutes; but Experience teaches us, that its Revolution takes up 25 Days and $\frac{1}{2}$, as we have already ſeen; which makes a Diſproportion too obvious.

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* Abſtracting from the Vicinity of other Planets, and Comets.

To ſhew that this Objection has in it more Appearance than Solidity, it will be ſufficient to ſay that the ſolar Atmoſphere is ſeparated into two Parts by a Vacuum ſo large, that the ſuperior Part can have no Communication with the inferior. Now as this Separation permits the inferior Atmoſphere to follow the Motion of the Sun round his own Axis, and to have the ſame periodical Time, it gives us a Right to maintain that the ſuperior Part, that it may not fall upon the inferior, has need of a planetary Motion, whoſe centrifugal Forces may counterbalance the centripetal. Every one then muſt be obliged to allow, that this ſuperior Atmoſphere ought to have different Degrees of Velocity in its different Parts; otherwiſe the loweſt would continually deſcend toward the Sun, and the higheſt in like manner might be elevated above Saturn.

Of COMETS.

Sir *Iſaac Newton* was the firſt that gave us a true Idea of the Comets Motion. Nevertheleſs Mr. *Caſſini*, the Father, had before found the way to predict their apparent Situation, when they are not too near the Sun. For, though he knew very well that their Motion is curvilineal, he yet ſuppoſed the Curvature to be ſo little ſenſible, that it might be look'd upon as a right Line; and by the Help of this Suppoſition, he found out a Calculation that differs little or nothing from Sir *Iſaac*'s; ſince the more the equal Segments of a Parabola remove from its Summit, the more they approach to a right Line.

When Sir *Iſaac Newton* invented the Hypotheſis of the parabolical Motion of the Comets *, to render its Calculation more geometrical and leſs perplex'd, he did not actually believe that the Curvatures of their Way were true Parabola's. On the contrary, in the 42d Propoſition of the 3d Book of his Philoſophy, he teaches the manner of finding by Approximation the grand Axis of their elliptical Orbits; with this Reſtriction however, that theſe Orbits are of a Figure ſo oblong, that we cannot ſee them all entire. We do not ſee the Comets therefore, but when they are in their Perihelia, becauſe all the reſt of their Courſe is made in Regions ſo remote, that our Sight cannot extend ſo far. What we ſee of the Orbit of a Comet, is often not equal to an hundredth Part of what we do not ſee. For as the Comets do not uſually begin to appear till they are deſcended to a Diſtance nearer the Sun than Jupiter, and farther from him than Mars. When they return into the ſuperior Regions, and attain a Diſtance from the Sun equal to that of Jupiter, their Light is ſo weak that it is perceived with the utmoſt Difficulty.

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* It was found to be matter of Fact from Obſervations, and no Hypotheſis invented by him.

As a Parabola is nothing elſe but an Ellipſis, whoſe Center is infinitely remote from its Focus, this Term is uſed, according to Sir *Iſaac*'s Rules, in the room of Ellipſis, when the preciſe Meaſure of the two Axes is not known, provided that the greater Axis exceeds the leſſer at leaſt 20 Times. Otherwiſe, it would not only be a conſiderable Fault to prolong the parabolical Motion beyond the Diſtances in which Comets are viſible, but we ſhould moreover deprive ourſelves thereby of the Hope of ever ſeeing them again.

Thus the Motion of the Comets round the Sun ſo far reſembles that of the Planets, that though the former approach much nearer that Luminary than the latter, they are not liable to impinge upon him, when the Curve of their Motion becomes perpendicular to its Diſtance. For the centripetal Force being leſs than a third, in proportion to the Diſtance of the Sun and the Velocity of the Perihelion, the Planet or Comet is no ſooner arrived at its greateſt Proximity to the Sun, but it begins to recede from that Luminary again *.

Why the Comets and the Planets do not impinge upon the Sun in their Perihelia.

Its Atmoſphere, Duration, Tail, and Return, are the moſt remarkable Particulars relating to a Comet.

The Atmoſphere of a Comet differs from that of an ordinary Planet, in that it is larger in proportion to the Body it ſurrounds. Some of them have 15 Times as much Diameter as the Comets themſelves. Likewiſe the ſame Atmoſphere is not always equally extended, becauſe it diminiſhes and increaſes by Fits.

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* But when its near the Aphelion the centrifugal Force is far greater than the attractive Force, but all on a ſudden the attractive Force exceeds the former.

It is not well known yet, whether theſe Diminutions and Augmentations return regularly at the ſame Diſtances from the Sun and the Perihelion. For, according to the Obſervations of *Hevelius*, cited by *Newton*, theſe Atmoſpheres diminiſh in proportion as they come nearer the Sun, and augment according as they remove from him. On the contrary, Mr. *de Mairan* aſſures us, that they encreaſe on approaching the Sun, by the Parts of the ſolar Atmoſphere that they carry away with them as they paſs along: Both theſe Opinions ſeem founded on this, that the Atmoſpheres of the Comets probably diminiſh till they meet that of the Sun, from which they acquire new Materials. Moreover, theſe Atmoſpheres, containing an Air like ours, muſt always occupy more Space when they deſcend towards the Sun, than when they aſcend from him; becauſe this Air rarifies extremely when they deſcend, and condenſes in like manner when they aſcend.

The Duration of the Comets is proved, according to Sir *Iſaac*'s reaſoning, by the Degrees of Heat they undergo in their Perihelia.

This Philoſopher made a Calculation, that the Comet in 1680, which paſſed by the Sun's Surface at the Diſtance only of a 6th Part of his Diameter, muſt contract a Heat 2000 times greater than that of red hot Iron. Whence he concluded that this Body muſt be very compact, and as antient as the World; otherwiſe it could not have reſiſted the Rays of the Sun, in that Proximity, but muſt have evaporated.

As the Sentiment of Sir *Iſaac* is a kind of Paradox to thoſe who have made no Progreſs in theſe Matters, it is proper to ſee how he ſupports it. The Line compriſed between the Center of the Sun and the Comet in Queſtion, in its Perihelion, was to the Radius of the Earth's Orbit as 600 to 100,000. The Heat perceived on Earth then, was to that of the Comet as 360,000 to 10,000, 000,000, or as 1 to 28,000. Now as the greateſt Heat in Summer is to that of boiling Water but as 1 to $3\frac{1}{2}$, and as this laſt is yet four Times leſs than that of red hot Iron, he found that the Iron's Heat was to that of the Comet as 14 to 28,000, or as 1 to 2000.

If a Ball of red hot Iron loſes its Heat in one Hour, and the Time neceſſary to cool the heated Spheres be in proportion to their Diameters and Degrees of Heat; it will require 108 Millions of Years to cool the Body of that Comet, provided it be ſo large as our Earth.

Why the Orbits of the Comets are ſo excentrical.

This Reflection diſcovers to us, and makes us equally admire, the Wiſdom of the Creator. Nothing could ſubſiſt in the Comets, if they had not a Heat ſufficient for the Preſervation of their Matter. Nature, to the End ſhe might give them as much Heat as they have need of, even in Regions the moſt remote, where a circular Motion, or one but little excentrical, would have deprived them of the Sun's Heat, has augmented ſo conſiderably their Excentricities, that they contract ſuch a Heat in a very ſhort Time, as makes them enjoy a temperate Warmth during the reſt of their Revolution. But if, on the other Side, there are animate Creatures in the Comets, as Mr. *Huygens* has proved there are in the Planets, they muſt of neceſſity retire into the interior Cavities of theſe Comets, to ſecure themſelves from that general Conflagration on their exterior Surfaces.

To conſider the irregular Figure of ſome Comets, one would judge that they do not turn upon their Axes; becauſe they cannot have this Rotation without having at the ſame Time a ſpherical, or a ſpheroidical Figure, and one Body only encloſed in their Atmoſphere. But ſome of them have been ſeen, that were neither exactly ſpherical nor ſpheroidical; others, that ſeemed to be an Aſſemblage of divers Bodies, of different Figures and Magnitudes; which no Ways agrees with a diurnal Motion, and renders the Poſition of their Axes extremely variable. Beſides this, their Tails, which are very unequal, and change almoſt every Moment, muſt either ſenſibly retard, or totally ſtop the Rotation in Queſtion; which has not yet been obſerved.

But if the Comets do not turn round on themſelves, the ſame Part, before and after their Conflagration, muſt be almoſt always expoſed to the Sun; and conſequently, one Part only of their Spheres can be habitable, becauſe that continually ſees the Sun, and the other is buried in a Night of many Years, or many Ages Duration; which, nevertheleſs, does not hinder but this Hemiſphere may have as much Heat as that which is illuminated. To explain this Paradox, we will add to what has been ſaid concerning their Excentricity, Page 334, that the Heat which they may receive from the Sun in their Aphelia, is not the 10,000 Part of what is felt at the Poles of the Earth; and that the Heat contracted in their Perihelia, muſt afterwards continue equal over all their Surface.

The Smoke which iſſues from the Comets, and which diſperſes itſelf in the Regions of Heaven that they traverſe, compoſes their Tails. They begin to form themſelves a little before the Comets arrive at their Perihelia, and from the Time that the Sun's Heat is intenſe enough to enflame the combuſtible Matters on their Surfaces, when the Smoke makes a Breach through their Atmoſpheres. It is true, however, that this Conflagration begins a little before we perceive the Smoke; but we conſider here only the Inſtant when we firſt diſcover their Tails.

They are never longer than when the Comets aſcend from their Perihelia, after which they diminiſh daily, even at the Time that they approach the Earth. From theſe Degrees of Augmentation and Diminution, the learned *Newton* found that the Tails of Comets were only Smoke. This was farther confirmed by their Direction, which extends always towards the Parts oppoſite to the Sun. We cannot give a more ſenſible Compariſon of the Times, than that which our Philoſopher has given, tho' it will require to be a little more circumſtantiated.

Let us conceive to ourſelves the Idea of a lighted Torch, with the Wick reverſed, that, by a projectile Motion, ſurrounds the Earth; all its Smoke will aſcend, and endeavour to get away from the Center of the Earth, notwithſtanding this Inverſion. Farther, this Smoke will ſo incline towards the Regions contrary to the Motion of the Torch, that the upper Part of it will ſeem to move more ſlowly than the lower: And, what is yet more remarkable, the Smoke will appear broader at Top than at the Bottom; as we ſee by that which iſſues out of Chimnies, which always occupies more Space than it did before. All this agrees perfectly with the Phænomena of theſe Tails. The kindled Part of a Comet, which is that towards the Sun, drives its Smoke to the Parts oppoſite to that Luminary.

This Smoke has always ſome Curvature at its Extremity, which is reclined, or beat backwards, in proportion to the Length of the Tail; the longer this, the greater the Curvature; and the Curve Extremity is alſo larger than that which adheres to the Body of the Comet. This Compariſon is ſo exact, that it leaves no Room to queſtion but the Tails of Comets are real Smoke, cauſed by their Conflagration on approaching the Sun.

Mr. *de Mairan* very ingeniouſly aſſigns another Cauſe to the Tails of Comets, which we ſhall here inſert, and endeavour to reconcile, as much as poſſible, with that which *Newton* has juſt now furniſhed us with. He remarks, that the Comets, as they paſs by the ſolar Atmoſphere, amaſs not only Particles which incorporate with them, as was before obſerved, but others alſo, which cannot ſuddenly follow the Comet, but detach themſelves from it, to form behind it a kind of Cone: Which Figure, according to that great Philoſopher, being rejected or puſhed by the celeſtial Matter, takes a Rout contrary to that of the Comet, as the Hair of a Man's Head, when he walks, or runs, againſt the Wind, takes a Direction contrary to that of the Head.

This Compariſon is good with regard only to the growing Tails of Comets, which have not yet attained their Perihelia. For the conic Collections from the ſolar Atmoſphere, drawn by the Comets after them, and the Beginning of their Smoke, which are the two Cauſes aſſign'd, as they both produce the ſame Appearances, ſo they both muſt have the ſame Effects upon our Sight. But beyond their Perihelia, the celeſtial Matter directs that which hangs on the Comet towards the Sun. Therefore no one ought to be ſurpriſed, if the Smoke of Comets is much more eaſily obſerved, than this little Aſſemblage of Matter that they carry along with them.

The periodical Revolutions of the Comets, is what at preſent engages the principal Attention of many Philoſophers. The Return of that which appear'd in 1682, may be predicted for the Year 1757 or 1758. There is the greateſt Room to believe it was the ſame that was ſeen in 1607; for there was ſo little Difference found between the Velocity, the Nodes, and the Inclination of the one and the other, that it may be conſidered merely as an Effect of the Attraction of the Planets, and the other Comets.

Mr. *Caſſini* has diſcovered, that almoſt all theſe tranſient Bodies have a Road different from that of the Planets. It has hitherto been unknown of what Conſequence this new Zodiac, and this periodical Return of the Comets, may be for the Preſervation of the human Species. Imagine, for Example, that there are fortuitous Bodies, which accidentally fall in with our Ecliptic: What a Diſaſter would it be for our Earth, if unhappily ſhe ſhould find herſelf in the ſame Point? The Idea of two Bombs, which burſt on claſhing together in the Air, is infinitely below what we ought to have of ſuch a Rencounter as this. Happily for us, it has been diſcovered that the greateſt Part of the Comets, in the Nodes of their Orbits, are much leſs remote from the Sun than either our

Earth, Venus, or Mercury. This is the whole Foundation of our Security, and hence we learn how many Thanks we owe the ſupreme Being for ſo great a Benefit.

The Comets, by their unexpected Returns, ſometimes produce Phænomena altogether ſurpriſing, when their Cauſe is unknown. Such was, according to Mr. *Whiſton*, that extraordinary Eclipſe of the Sun ſpoken of by *Herodotus*, which arrived in the Spring of the Year 4334 of the *Julian* Period, when *Xerxes* departed from *Sardis*, the Capital of *Lydia*, where he had ſpent the Winter. Such was alſo, according to *Wolf*, that of the Moon, which happened in the 14th Century, that celebrated Mathematician having ſhewn in his Elements of Phyſic, after *George Phranza*, that this Phænomenon could not happen naturally, the Moon being then in one of her Quarters. To conclude, ſuch was that of which *Gregory Abulpharachius*, an *Arabian* Author, makes mention in his Hiſtory of the oriental Dynaſties, where he remarks, that under the Emperor *Heraclius* the Sun appeared all over the Earth, for the Space of three Days, as red as Blood, which might well happen, by the Interpoſition of a Comet's Tail.

Of the FIXED STARS.

A ſeeming Contradiction of the Newtonian *Syſtem, with regard to the fixed Stars.*

As Sir *Iſaac Newton*'s Syſtem ſeems to contradict itſelf with regard to the fixed Stars, which, according to him, attract one another, and yet remain immoveable; we muſt begin with explaining his Sentiment, and ſhewing, that it does not imply any Contradiction at all.

The Diſtance that there is between one fix'd Star and another is ſo immenſe, that they could not deſcend towards each other ſo much as one ſingle League in a Year. This is what will be ſeen in the following Calculation. 1ſt. Ponderous Bodies, according to our Computations, Page 244, deſcend (if we keep to round Numbers) at leaſt 1,260,000 Feet upon the Surface of the Sun, during the firſt Minute. 2dly, According to *Huygens*, the neareſt fixed Stars to the Sun are diſtant 28,000 Semidiameters of the Earth's Orbit, or thereabouts, that is to ſay, above 5,600,000 ſolar Semidiameters, the Square of which is 31,360,000,000,000. The neareſt fixed Star to the Sun, therefore, advances towards him the $\frac{1260000}{31350000000000}$ Part of a Foot, during the firſt Minute. But if, inſtead of this Fraction, we reckon the $\frac{1}{25000000}$ Part of a Foot, we ſhall find for the firſt Year 11,000 Feet, which is very near the exact Number, with regard to the Sum total.

Sir *Iſaac Newton* has demonſtrated, in the 12th Propoſition of the 3d Book of his Philoſophy, that the common Center of Gravity of our planetary Syſtem, would be diſtant one ſolar Semidiameter from the Center of the Sun himſelf, that is about 4,000,000,000 Feet, if all the Planets were on one Side, and this Luminary on the other. What Diſproportion then, between the Diſorder of the Sun, occaſioned by the Planets that encompaſs him, and that which proceeds from the fixed Star that is neareſt to him! even no leſs than between 11,000 and 4,000,000,000 Feet!

Now as the Sun is ſometimes on one Side of the univerſal Center of his proper Syſtem, and ſometimes on the other, and as the ſame thing happens to every fixed Star, with regard to the unknown Planets that ſurround it, the manifeſt Reſult is, that theſe luminous Bodies are reciprocally attracted by Forces much weaker than thoſe which ſometimes draw them from each other. Theſe Viciſſitudes then, of Proximity and Diſtance, are what always retained the fixed Stars in their natural Situation, without any Poſſibility of their ever falling upon one another.

As certain fixed Stars, which, according to the Obſervations of *Montanaro*, have diſappeared within ſome Years paſt, and have not deſtroy'd the Stability of thoſe which remain, it may be proper to enquire what may be the Cauſes of their diſappearing *. The celebrated *Wolff* ſpecifies three of theſe Cauſes in his Phyſicks. 1ſt. They may, according to him acquire Motion, and thereby withdraw themſelves from our Sight. 2dly, By falling back into Chaos, they may burſt, and evaporate entirely. 3dly, They may loſe their Light, either altogether, or in ſuch a Degree as to make them inviſible to us.

The firſt of theſe Cauſes appears by ſo much the leſs probable, as the Attraction of the fixed Star, which ſhould diſappear, would become ſtronger, and would precipitate all the Bodies that might environ it, one upon another. The ſecond is not more probable, ſince this pretended Diſſolution muſt change the reciprocal Gravitation of the Stars that were neareſt to that which ſhould evaporate; ſo that, for the future, they would have nothing to keep them in Equilibrium. We will therefore adopt the third, becauſe by ſuppoſing the Stability of the * fixed Star, we ſuppoſe it to preſerve all its attractive Force.

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* The Stars that diſappear cannot be called fixed; they are more likely Planets revolving about a fixed Star, which appear when they come near the Earth, with their luminous Part towards it, as that in the Whale, the Swan, and Hydra, which have their periodical Returns.

The ſame Judgment ſhould be made of the periodical Returns of the Apparition and Occultation of certain Stars, that have been obſerved in the *Whale*, the *Swan*, and the *Hydra*. For tho' the Part which is towards us be more or leſs luminous, and we ſometimes loſe Sight of it entirely, yet they never quit their Places, but their Attraction continues to preſerve the Equilibrium of the Univerſe.

It follows, from all theſe Arguments, that the reciprocal Gravitation of two fixed Stars, does not diminiſh preciſely in the inverſe or reciprocal Proportion of the Squares of their

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* Then they diſappear, becauſe their Light is put out; but what puts it out?

Diſtances, eſpecially near the common Center of their Gravity. It follows alſo, that the Law of Gravitation may vary, as may be ſeen at the End of Chap. VII. where the different ſorts of Attraction are ſpoken of. The Action of the Loadſtone upon Iron * in inverſe Reaſon of the Cubes of their Diſtances, and that of tranſparent Bodies upon the Rays or Atoms of Light, ſufficiently prove, not only the Poſſibility, but the Reality of what is here advanced.

* Action of the Loadſtone on Iron, being mechanical, cannot be called Gravitation.

CHAP. XXV.

Of the ſecond Inequalities of the Motion of the Satellites, and the Phænomena that depend thereon.

AFTER having given the Reader, in the XXI^{ſt} Chapter, ſeveral Particularities of the Moon's Motion, to eſtabliſh the Neceſſity of Attraction; it remains that we ſhould ſhew in this, that the Theory of theſe Inequalities, cauſed by this Mechaniſm, is entirely conformable to Obſervations.

Sir *Iſaac Newton* has aſſigned three Cauſes of theſe ſorts of Irregularities. He maintains, 1ſt. That the Force which draws the Moon towards the Earth, is leſs than that which draws theſe two Planets towards the Sun; 2dly, That, conſidering the Orbits as exactly circular, the Force which attracts the Earth towards the Sun is always equal, whereas that which draws the Moon towards the ſame Luminary is greater in her Conjunction than in her Oppoſition: and 3dly, That the Lines of Attraction, which tend towards the Sun, contract themſelves in Proportion as they come nearer him, and always augment the Gravitation of the Moon towards the Earth, eſpecially when that Planet is in her Quadratures.

If we ſuppoſe, for Example, that the Moon is in Conjunction with the Sun; it will appear, that, by her Gravitation only towards the Earth, ſhe will deſcribe, in 10 Hours 20 Minutes, a ſmall Arch, of 100 ſuch Parts, whereof 1000 compoſe the Radius of her Orbit, and 336,000 make her Diſtance from the Sun. Now if, during this Time, the Moon deſcribes 100 Parts of her Radius, it follows that (according to the Rule of circular Motion, mentioned Page 331, Line 7.) as 1000 Parts of this Radius are to 100 (a Line which differs little from the Arch in Queſtion) ſo the Number 100 is to 10, the uniform Deſcent of the Moon towards the Earth. But if we would determine the Deſcents of the Earth and the Moon towards the Sun, we muſt conform to the Rules given Page 233, and proceed by this ſhort Operation. 1ſt. As 1 (the Moon's Diſtance from the Earth) divided by the Square of a periodical Month, is to 337, divided by the Square of a Year; ſo 10 (the Deſcent of the Moon towards the Earth) is to 19, the Earth's Deſcent towards the Sun. 2dly, As the Square of 336,000 is to the Square of 337,000; ſo 19 (the Earth's Deſcent towards the Sun) is to $19\frac{12}{108}$, the Moon's Deſcent towards that Luminary. There muſt then be $\frac{12}{168}$ of one ſingle Part of the Moon's Radius, taken from 10 Parts of the ſame Radius, to find her true Deſcent towards the Earth; which will in Fact be only $9\frac{142}{108}$; whereas it would be 10, without the particular Action of the Sun upon that Satellite. By the ſame Reaſon the Moon's Diſtance from the Earth, which was laid down at 1000 Parts, will be found to conſiſt of $1000\frac{12}{168}$ Parts; which contributes yet more to the Diminution of her Gravity.

Whilſt the Moon is yet ſo little diſtant from her Conjunction, the Force which impels her towards the Line of the Syzigiæ is not at all conſiderable; but it augments in proportion as this Planet comes nearer her Quadrature. When, on the contrary, ſhe has attained her Quadrature, that ſecond force, which acts in the ſame Senſe as her Gravity towards the Earth, drives her always towards our Globe, till, being in her Oppoſition, ſhe finds herſelf diſtant from it only 1000 Parts.

By the Mixture of theſe two Forces, the Diſtance of the Moon from the Earth, in her Quarters, will be from 1023 to 1024 Parts, continuing the Calculation, which we have before ſketch'd out, and remembring the Obliquity ariſing from the Configuration of that Satellite with the Sun. As for the reſt, we do not here any longer admit of Excentricity; if we did, the Orbit would be always oval, tho' of different Breadth and Figure, according to the Capacity of the Angle compriſed between the two Lines of the Apſides and the Conjunctions. For ſuppoſing this Angle nothing, the Excentricity becomes larger than if we ſuppoſe it of 90 Degrees; ſince in the firſt Caſe, the grand Axis is 2000, and in the ſecond, 2047. Our Dimenſions, it is true, are not the ſame with thoſe of Sir *Iſaac Newton*: But as that great Man acknowledges, towards the End of his Preface, that his Lunar Theory hath its Imperfections, we have thought it ſufficient to keep cloſe to his Principles, without ſubjecting ourſelves to his Menſurations.

As to the Satellites which compoſe Saturn's Ring, we ſhall find, by a ſimilar Calculation, that the grand Axis of their Orbit is to the ſmall, as $1000\frac{1}{94}$ to 1000, and that, conſequently, this Orbit is 2,250 Times leſs elliptical than that of the Moon.

But to ſatisfy thoſe who may doubt whether our Calculation be conformable to Obſervations, let us return to the Excentricities, which we have only pointed out before, and ſhew, by a new Computation, that they agree with the apparent Diameters, and horary Motions of the Moon.

When the Apſides fall in the Syzigie, the greateſt Excentricity of the Orbit being, according to the moſt famous Aſtronomers, to the mean Diſtance of the Moon, as 67 are to 1000, one may eaſily conceive that the Apogæon is diſtant from the Earth 1067, and the Perigæon 933. By the ſame Reaſon, when the Apſides are at the Quarters, the Excentricity in queſtion being but 44, and the mean Diſtance 1024, that of the Apogæon to the Earth ought to be 1068, and that of the Perigæon 980.

Now the apparent Diameter of the Moon in her Apogæon, conſiſts (to count without Fractions) of 29 Minutes and 40 Seconds, and never varies more than from 1067 to 1068. On the contrary, it varies always in her Perigæon from 34 Minutes to 32½ Minutes, that is, in reciprocal Proportion of 933 to 980. Therefore the Diſtances of the Apogæon and the Perigæon are preciſely, according to our Calculation, in reciprocal Proportion of thoſe apparent Diameters, that have hitherto been found by Obſervation.

The Exactneſs of theſe Relations is no leſs proved by her horary Motion. For while the Areas deſcribed are equal, theſe Motions are always in reciprocal Proportion of the Squares of Diſtances. Thus, as the Square of 933 is to 29 Min. 20 Seconds, the Horary of her Apogæon; ſo is the Square of 1067, agreeably to Obſervation, to 38 Minutes, the Horary of her Perigæon in the Syzigie. And if the Square of 980 produces 29 Min. 20 Sec. that of 1067 will produce, conformably to Obſervation, 35, for the Horary of her Perigæon in the Quarters.

It appears alſo, that, by the ſame Laws of Gravitation towards the Sun, the Moon, which is not in the Ecliptic, ought to approach it even to the Syzigiæ; becauſe, according to the Angle of her Orbit with ours, her Latitude continually grows leſs than it ought to be. This Latitude then diminiſhes every Moment; and whereas in the Quadratures, near the Nodes, it was of 5 Deg. 18 Min. it is barely of 5 Deg. both in the Conjunctions and Oppoſitions; which renders the Surface of the Orbit curvilineal. If, on the contrary, the Nodes are in the Syzigiæ, the Action of the Sun doth not diminiſh the Latitudes, the Angle in queſtion remains always the ſame, and the Orbit becomes a plain Superficies. As to their Motion, it is then extremely ſlow, becauſe the Action of the Sun, which, during a pretty conſiderable Space of Time, is almoſt parallel to the Diſtance of the Moon and the Earth, never ſlackens at all: But it is not the ſame in the Quadratures, where they have a conſiderable Retrogradation. For the Moon meets them every Month about three Hours ſooner, eſpecially at the Middle both of her Increaſe and Decreaſe, where the Difference of her Gravitation, and of that of the Earth, towards the Sun, augments and diminiſhes more ſwiftly than any where elſe.

Motion of the Terreſtrial Poles, Page 258.

The Preceſſion of the Equinoxes, as well as the Retrogradation of the Nodes, is moreover an Effect of theſe Irregularities, tho' much more ſlow; becauſe the Quantity of terreſtrial Matter, which is under the Equator, differs very little from that of the Meridians; and becauſe that little *Exceſs*, under the Equinoctial, ſupplies the Place of a Satellite, or a Ring, ſuch as that about Saturn.

There are ſome other Cauſes, which render the Motion of the Satellites a little irregular, but whoſe Effect is not conſiderable, except with regard to themſelves. It has been remarked, that the Apogæon of the firſt and fourth Satellite of Jupiter is conſtantly the ſame with that of their central Planet; and that it is not till after many Revolutions of this latter, that the Orbit of the 3d Satellite returns to the ſame Inclination. Thus the Nodes of theſe four little Bodies have not varied, at leaſt ſince they have been obſerved, which is more than a hundred Years. In a Word, all theſe Inequalities are far ſhort of thoſe of the Moon; not to mention her Rotation, which differs conſiderably from what ſome have thought they have perceived in the other Satellites.

After having run thro' all theſe different Motions, we can by no Means excuſe ourſelves from ſhewing their Cauſe; which is not ſo obſcure as many People may have imagined. Take it in a few Words. The reciprocal Attraction of theſe Planets, occaſioned by their Number and Proximity, is much ſuperior to the Action of the Sun upon them. By this it is eaſy to judge, that the Ring of Saturn muſt extremely diſorder the Satellites which make their Revolution round it, eſpecially the ſmalleſt and moſt excentrical of them. In like manner we may judge, that the Attraction of this Ring muſt conſiderably retard the Deſcent of Bodies upon the Surface of Saturn. In fine, the Example of the Flux and Reflux of the Sea, will not ſuffer us to doubt of this Truth. For it is a Conſequence of all that was ſaid in Chap. XVIII.

that the Gravity of the Center of the Earth towards the Moon is always the ſame; whereas the Waters that happen to be between this Center and the Planet, are there attracted with more Velocity, than when the diurnal Rotation of the Earth has tranſported them to the Point diametrically oppoſite.

This is what we had to ſay concerning the principal Effects of the *Newtonian* Attraction, ſuch as it was imagined by that famous Mathematician; by regarding it as the only Cauſe of the Refraction of Light, and as the firſt Spring of the Mechaniſm of the Univerſe. In Quality of a Philoſopher, it is true, he aſſigned to it an Empire in Nature yet much more extenſive, by reducing under its Laws all the Operations of Heat, the Compoſition and Decompoſition of Mixts, the Electricity that is remarked in Amber, the Diamond, Spaniſh Wax, and other Bodies of like Nature: But we will not enter into this Detail, becauſe it would carry us too far, and has beſides no Relation to Geometry, which we have never loſt Sight of in all this Work. We will finiſh it then, without ſpeaking of the double Refraction of the Iſlandiſh Chryſtal, of the Diminution of the Denſity and Elaſticity of the Air, of the Tenacity of viſcous Mediums, in which any Body whatſoever may move; and many other ſimilar Matters. It is for the ſame Reaſon that we have but lightly touched on certain Things, ſuch as the Preceſſion of the Equinoxes, and the periodical Return of the Tides; Phænomena, in which there muſt be yet ſome other mix'd Cauſe, that has been hitherto unknown. For if we are ignorant of what occaſions the Equality of the Motion of Jupiter's equinoctial Points, and of the Nodes of his Satellites, we are no leſs ignorant why the Flux and Reflux of the Sea follows rather the Mean, than the true Motion of the Moon. At leaſt we muſt confeſs, that the Concurrence of the Sun's Action with that of a Satellite, upon a principal Planet in the Syzigiæ, or their Difference in the Quadratures, cannot furniſh us with the Reaſon of theſe two Effects.

F I N I S.

Explanation of the hard Words uſed in this Treatiſe.

A.

ANecdote, is a ſecret Hiſtory, or private Memoirs.

Attraction is the Effect of a Power in Matter, by which all Bodies tend to one another, with a Force in Proportion to the Quantity of their Matter.

Atmoſphere is all that Air that ſurrounds the Earth, which riſes 50 Miles above its Surface, as appears by the Mercury in the Barometer.

Aries is the firſt of the 12 Signs in the Ecliptic, each containing 30 Degrees.

Area is a Space incloſed on any Superfice.

C.

CUBE is a ſolid Figure, in which all the Dimenſions, Breadth, Height and Depth are equal, or a Number ariſing from its Square, multiplied by the Root, as 27 comes from 9 by 3.

Convex is the Outſide of a curve Line, or Superfice.

Concave, the Inſide thereof.

Cone is a ſolid Figure, wherein its circular Baſe tapers, till it come to a Point, as a Sugar Loaf.

Converge. Lines are ſaid to converge, when they come nearer to one another the more they are continued, and do at laſt meet in a Point.

Catoptricks is a Science, in which the Laws of the Reflection of Rays are explained and demonſtrated, as why an Object appears in one Part of a Looking-Glaſs, and not in another, &c.

Cataract is a Diſtemper in the Eyeſight, ariſing from a thick Cruſt on the Pupil of the Eye.

Centrifugal Force, is that whereby Bodies moving circularly, tend to go from the Center of the Motion called ſometimes a projectile Force.

Centripetal is a Force whereby Bodies tend to the Center of this Earth, or any ſpherical Body by Attraction, called ſometimes Gravity.

D.

Diverge. Lines are ſaid to diverge, when coming from a Point, they go further from one another the longer they are continued.

Dead Force, is that which inclines Bodies to Motion, tho' there be none, as a Stone preſſes with a dead Force to the Center of the Earth.

Diſc is that Part of a Globe that appears to our Eye, as in an Eclipſe of the Sun the Moon covers a Part or the whole of its Diſc.

E.

Ellipſis is ſuch an oval Figure as would ariſe by cutting a Cone through its two Sides obliquely, ſuch as that in our Tables that are near, but not quite round.

Equator is an imaginary Circle at equal Diſtance from the two Poles of the Earth, which if enlarged would reach to the equinoctial Line in the Heavens.

Ecliptic is a Circle cutting the Equator, with an Angle of 23 Deg. and 29 Min. through which the Sun ſeems to move in a Year.

F.

FOCUS is a burning Point near the middle of a Piece of Glaſs in the Form either of a Clobe, where the Rays of Light would meet, or of an Egg, if its longeſt Diameter were directed to the Sun, it is applied to a Point in the Axis of the Section of a Cone.

G.

GROUP, or Bundle, its applicable to a Pencil of Rays that come from the Sun, which may contain either the ſame or different ſorts of Rays.

H.

HEmiſphere is the half of a Globe, either of the Earth or Heavens, *&c.*

I.

INdefinite is that which, tho' it hath Limits, yet they cannot be conceived by us.

Inflection is bending, which the Rays of Light make in paſſing by the Edges of ſharp Bodies.

L.

LIVING Force is that which actually produces ſome Motion.

Latitude is the Diſtance of a Place from the Equator in Degrees and Minutes.

Longitude is the Diſtance of the Meridian of a Place from that which is called the firſt Meridian, counted on the Equator in Degrees.

M.

MIcroſcope, is an Inſtrument in which are two or more convex Glaſſes, through which an Object is greatly magnified.

Meridian, is an imaginary Circle paſſing through both Poles, which may be conceived either in the Heavens, or on the Earth; if it paſs through our Place or over us, it is called our Meridian.

N.

NODES are the two Points in which one great Circle cuts another, as the Orbit of the Moon cuts the Ecliptic in two Points, that are the Moon's Nodes.

O

O*RBIT* of the Moon is not the Circumference of her Diſc, but the Circle her Center deſcribes round the Earth, or rather the Ellipſis; Allowance being made by the Attraction of ſurrounding Bodies.

Oſcillation is the ſame with Vibration, or ſwinging of a Pendulum, or any heavy Body, hung on a Point.

Opticks is the Doctrine and Viſion in which the Parts of the Eye, their Uſe and Manner of ſeeing, is deſcribed

P.

P*LANET* is a dark Globular Body, revolving about the Sun, or ſome other Planet, which being illuminated by the Sun, appears luminous as the Planets Jupiter, Saturn, Mars, Venus, that appear like fixed Stars, but are not.

Plenum is a Space quite void of Matter.

Parallellogram is a Figure of four ſtraight Sides parallel, and the two oppoſite Sides equal.

Polar Circles are ſmall Circles, within 23 Deg. and ½ of each Pole.

Priſm is a ſolid Figure, incloſed by parallel Planes, of the ſame Length, and is called either triangular or ſquare, according as the two Ends are. In a triangular Priſm of Glaſs the different Kinds of Rays are parted by their different Rarefactions.

Pores are ſmall Spaces in Bodies thought to be void, or that do contain a fine Fluid.

R.

R*Etina* is a fine Net on the back Part of the Eye, on which the Images of Objects are painted.

Ray of Light is a moſt ſwift Motion of its Atoms from the Sun, tho' it comes alſo from ſome Flies, rotten Wood, dry'd Fiſh.

Refrangibility is a certain Power, by which a Ray of Light is turned out of its Courſe paſſing from one Medium into another, as from Air to Glaſs or Water, which Power ariſes from ſome Quality in the Ray which denominates it either Red or Green, *&c.*

Ratio is the Proportion between one Number, ſuperfice, or Body and another; two Ratio's are ſaid to be inverſe or reciprocal, when more gives leſs, or leſs gives more.

S.

S*Atellite* is a ſecondary Planet, revolving about a primary one, as thoſe of Jupiter, Saturn, and that of the Moon about our Earth.

Spheroid is an Egg-like Figure, in which one Diameter is longer than the other.

Square Number, is the Product of one Number multiplied by another, as 9 is the Square of 3, and 3 the Root of 9.

Solſtice is the fartheſt Point the Sun goes to from the Equator, either North or South.

Sine of an Angle or Arch, is a Line from the End of it perpendicular to the Diameter.

T.

T*Rranſparent* is that which admits the Light to paſs eaſily through it.

Teleſcope is an Inſtrument in which are two or more Glaſſes, of ſuch a Figure, that the Rays are brought thereby to our Eye, ſo as to ſee Objects far off diſtinctly, and as it were near us.

V.

V*Acuum* is a Space in which there is no Matter, either in the Pores of Bodies, or beyond the Limits of the World.

Z.

Z*Enith* is the Point in the Heavens exactly over our Head, and Nadir the Point oppoſite to it.

Zodiac is a broad Circle in the Heavens, in which all the Planets move, being about 8 Deg. broad on each Side of the Ecliptic.

Zone is all that Space comprehended either between the Poles and Polar Circles, and is called the frigid Zone; or between the two Tropicks, which is called the torrid or burning Zone; or between the Tropicks and the polar Circles, and is called the temperate Zone.

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